Health and flight safety implications from exposure to contaminated air in aircraft

Author:
Michaelis, Susan

Publication Date:
2010

DOI:
https://doi.org/10.26190/unsworks/23524

THE UNIVERSITY OF
NEW SOUTH WALES

Health and Flight Safety Implications from Exposure to Contaminated Air in Aircraft

by

Susan Michaelis

A thesis submitted in fulfilment of the requirements for
the degree of Master of Doctor of Philosophy
School of Risk and Safety Sciences
Faculty of Science
The University of New South Wales

September 2010

0.1 Thesis Administration

0.1.1 Thesis Cover Sheet

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Title: Health And Flight Safety Implications From Exposure To Contaminated Air In Aircraft.

Abstract

This thesis examines the six-decade use of unfiltered aircraft bleed air, taken from jet engines to supply breathing air in the flight decks and passenger cabins of commercial and military transport aircraft. During this time, numerous flight safety issues and adverse effects from exposure to contaminated bleed air have been reported. The research undertaken in this thesis examined previous investigations into these matters and the consequences of using bleed air on flight safety and crew and passenger health. This research examined: (a) health issues reported by aircrew as a consequence of exposure to contaminated bleed air whilst flying by way of several descriptive surveys; (b) various aviation air monitoring studies previously undertaken were reviewed to assess the knowledge base of the chemicals present during contaminated air events; (c) air sampling data were evaluated for their usefulness in determining any potential adverse health effects; (d) a review was undertaken of the frequency of contaminated bleed air events; (e) a review was undertaken of some of the information known by the aviation industry and others about contaminated bleed air. Analysis of the evidence that bleed air, contaminated by synthetic jet engine oils and hydraulic fluids, is a regular and normal occurrence and far more common than previously accepted and is a consequence of the current bleed air system design. There are significant short and long-term health effects being reported as a direct result of documented exposure events that validate claims of adverse health effects in exposed individuals. The thesis argues that the precautionary principle, occupational health and safety guidelines and aviation regulations are being ignored by the aviation industry, who continue to claim that cabin air is safe. The systemic misuse of available data is widespread, secondary to commercial objectives, and places passenger and crew health and flight safety at serious risk. The thesis concludes that the use of bleed air on commercial aircraft with no form of contaminated air detection or filtration system present should be discontinued. The risk to health and flight safety is no longer acceptable.

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0.1.1 Originality Statement

I hereby declare that this submission is my own work and to the best of my knowledge it contains no materials previously published or written by another person, or substantial proportions of material which have been accepted for the award of any other degree or diploma at UNSW or any other educational institution, except where due acknowledgement is made in the thesis. Any contribution made to the research by others, with whom I have worked at UNSW or elsewhere, is explicitly acknowledged in the thesis. I also declare that the intellectual content of this thesis is the product of my own work, except to the extent that assistance from others in the project's design and conception or in style, presentation and linguistic expression is acknowledged.

Susan Michaelis

Date

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1.1 Acknowledgements

There are in fact so many people I would like to thank for assisting me on this thirteen year quest to set the record straight, however of course I can only single out a select few as follows. I would like to acknowledge:

- Professor Chris Winder of UNSW, my colleague and Masters and now PhD supervisor;

- Tristan Loraine, former UK airline pilot and Co-Chair of the GCAQE who has given more than most would know to highlight the contaminated air issue to the world. Without Tristan's will, never failing vision and drive, the true extent of this issue would without doubt have remained hidden from the world still today;

- Judith Murawski, Industrial Hygienist at the Association of Flight Attendants, AFL-CIO and Co-Chair of the GCAQE. Judith is a body of knowledge at any time of the day and whose commitment to the issue is exemplary.

- Judy Cullinane who worked tirelessly with me to generate the Australian Senate Inquiry and so much more and Senator John Woodley for listening to our concerns;

- Many other crew around the world and members of the GCAQE for which I am the head researcher – This would not have happened without your support and belief;

- Crews and their families who shared their experiences and who helped broaden our knowledge of these matters;

- International experts who have independently and critically examined the facts. They have given their precious time to investigate and understand these matters. This has been invaluable. These people know who I am referring to;

- The University of New South Wales: For believing in me and allowing me to recommence my research as a PhD after having ceased the MSc on 2005;

- Both Australian pilot unions, Lawrie Cox at the AFAP listened to me and supported me right from 1997 and I am grateful for that; Ian Woods and AIPA

believed in me to the extent that in 2007 they made me their honorary cabin air quality consultant;

- My family for their belief in me, my late mother for giving me the strength and my parents for giving me the opportunity of vision.

Thank you all.

Susan Michaelis

Date

1.2 A Personal Note

Twenty four years ago when I first learnt to fly in Melbourne, I never thought I would be completing a PhD in issues relating to contaminated air in aircraft and which were responsible for my career being cut short at the age of 34.

I recall soon after having to stop flying in 1997, walking into the School of Safety Science at the University of New South Wales in Sydney with two colleagues and asking for help. I had been advised that Professor Chris Winder, an Occupational Toxicologist at UNSW may be able to shed some light on the hazards of breathing oil fumes in aircraft. That was to be the beginning of a thirteen year quest to understand the implications of aircraft contaminated bleed air.

Soon afterwards I was provided with a folder of documentation on what another Australian airline, Ansett Australia had known for years. The documentation revealed that the oily smell I and others had assumed was just a routine smell in the aircraft we flew, was in fact an industry wide problem known to many, but not me.

The more I researched this issue, the more the volume of data grew and my depth of awareness expanded and triggered my desire to undertake further research.

However I have not been alone in this quest. Professor Winder at UNSW has given untold years to address this problem that we now know affects anyone who flies in a commercial aircraft, in one way or another. There have been many others who have given so much to uncover what some in the airline industry have deemed as ‘acceptable so long as the frequency remains low’. I am indebted to UNSW for providing me the means to allow me to gather the data and provide a learning platform hopefully for the interests of aviation health and safety worldwide.

I had wanted to fly since I was young and when I discovered the opportunity was there, I grabbed it with both hands in 1986 and studied hard to become a commercial pilot. In 1987 I was awarded the CASA Sir Donald Anderson Award for academic merit but little did I know my drive to study and learn would only ten years later be rekindled when I became unwell. Perhaps this answers the question I am so often asked: Why me?

However I am not alone and the quest for the truth by Professor Winder, my colleagues and I, specifically, Tristan Loraine and Judith Murawski, the Co-Chairs of the GCAQE, has broadened my horizons, given me new opportunities and allowed me to, I trust make a difference.

I recall talking to my colleagues on the flight deck about how I would get a computer one day. Little did I realise that it was my first computer that I eventually purchased that I used to unravel the issue of contaminated air further. This led from the issue being one that I could just manage from where I lived in Sydney to becoming a global one in which I discovered there were other like-minded people out there, who also gave all they could to resolve this issue.

The thirteen-year journey to gather and record the vast depth of information available on this global health and safety problem has not come without a price. I still suffer chronic ill health every day, thirteen years after ceasing flying professionally and this research and requests for support on this issue by other crews does not help my health. However, I still strive for answers and the knowledge I have gained, and the help that I have given, has made me a stronger person and helped others.

While I had commenced gathering data in 1997 and writing papers, I formerly accepted the challenge to complete an MSc on cabin air contamination in 2002. However after undertaking so much research, helping to make an AFAP/AOPIS documentary about the issue and trying to improve my health, I felt I could not manage the MSc and asked UNSW to withdraw in 2005. I know this was a disappointment to many, however in 2007 after publishing my research in the Aviation Contaminated Air Reference Manual and aware that the issues remained unresolved, I agreed to recommence my studies at UNSW as a PhD in 2008. I thank those who stuck by me and encouraged me.

Finally I thank all those that have put up with my all consuming quest to sort out something that is so clearly not right. It is also ironic that as a commercial pilot no longer able to fly and being unwittingly diverted into research, that in the week I completed the first draft of this PhD; Boeing first flew the Boeing 787 with *'bleed free'* technologies. Technologies that many others and I had been requesting for so many years and which I wish had existed on the aircraft I flew. In the week I submitted my final thesis to UNSW in September 2010, my colleague and former flight attendant Joanne Turner, made history by winning her long fight for justice and legal case in the High Court of Australia. Two amazing coincidences.

1.3 Abbreviations Used in this Thesis

A300	Airbus A300
A319	Airbus A319
A320	Airbus A320
A321	Airbus A321
A330	Airbus A330
A340	Airbus A340
A350	Airbus A350
A380	Airbus A380
AAFA	Australian Association of Flight Attendants
AAIB	Air Accidents Investigation Branch (UK)
ACER	Airliner Cabin Environment Research (US)
ACGIH	American Conference of Governmental Industrial Hygienists
AD	Airworthiness Directive
ADFA	Australian Defence Force Academy
Aerotoxic.org	The Aerotoxic Association
AFA	Association of Flight Attendants (US)
AFAP	Australian Federation of Air Pilots
AGAL	Australian Government Analytical Laboratories
AIPA	Australian and International Pilots Association
AIR	Aerospace Information Report or Aero International Regional
ALAEA	Australian Licensed Aircraft Engineers Association
ALF 502	Turbofan engine produced by Lycoming, AlliedSignal and then Honeywell Aerospace used on the BAe 146
AME	Aviation Medical Examiner or Aircraft Maintenance Engineer
A-NPA	Advance Notice of Proposed Amendment (EU)
AOC	Air Operator's Certificate

AOL	All Operator Letters
AOM	Aircraft Operating Manual or All Operator Message
AOPIS	Aviation Organophosphate Information Site (NGO)
APA	Allied Pilots Association
APFA	Association of Professional Flight Attendants
APU	Auxiliary Power Unit
ARAC	Aviation Rulemaking Advisory Committee, (US)
ASCC	Australian Safety and Compensation Council (formerly NOHSC)
ASHRAE	The American Society of Heating, Refrigeration and Air Conditioning Engineers
ASIR	Aviation Safety Incident Report
AsMA	Aerospace Medical Association
ASR	Air Safety Report (UK)
ASRS	Aviation Safety Reporting System (NASA/FAA)
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATSB	Australian Transport Safety Bureau
ATSM	American Society for Testing and Materials
B707	Boeing 707
B717	Boeing 717
B727	Boeing 727
B737	Boeing 737
B747	Boeing 747
B757	Boeing 757
B767	Boeing 767
B777	Boeing 777
B787	Boeing 787
BAe 146 RJ	British Aerospace 146 RJ

BAe 146	British Aerospace 146
BAe ATP	British Aerospace ATP
BAe	British Aerospace Systems
BALPA	British Airline Pilots' Association
BASI	Bureau of Air Safety Investigation (Australia, now ATSB)
BASSA	British Airlines Stewards and Stewardesses Association
BChE	Butyrylcholinesterase
Bleed Air	Hot compressed air taken from turbine engines
BNA	Beta-Naphthylamine
BRE	Building Research Establishment (UK)
CAA	Civil Aviation Authority (UK)
CAAP	Civil Aviation Advisory Publication (Australia)
CAIR	Confidential Aviation Incident Reporting System (Australia)
CAP	CAA Publications (UK)
CAQ	Cabin Air Quality
CAR	Civil Aviation Regulation
CAS	Chemical Abstracts Service
CASA	Civil Aviation Safety Authority (Australia)
CASR	Civil Aviation Safety Regulations (Australia)
CBDP	Saligenin cyclic- o- tolyl phosphate
CFDT	Confédération Française Démocratique du Travail (France)
Cfm	Cubic feet per minute
CFR	Code of Federal Regulations (USA)
CMO	Chief Medical Officer
CO	Carbon monoxide
CO_2	Carbon dioxide
CoA	Certificate of Airworthiness
COHb	Carboxyhaemoglobin

COPIND	Chronic organophosphate neuropsychological disorder
COSHH	Control of Substances Hazardous to Health
COT	Committee on Toxicity (UK)
CPL	Commercial Pilot's Licence
CRM	Cockpit resources management
CS	Certification Specification
CUPE	Canadian Union of Public Employees
CV880	Convair 880
CV990	Convair 990
DAME	Designated Aviation Medical Examiner
DASH 8	De Havilland Canada Dash 8
DC-10	McDonnell Douglas DC-10
DC-8	McDonnell Douglas DC-8
DC-9	McDonnell Douglas DC-9
DETR	Department of the Environment, Transport and the Regions (UK)
DFT	Department of Transport (UK)
DOCP	Di-ortho-cresyl phosphate
EASA	European Aviation Safety Agency
ECA	European Cockpit Association
ECS	Environmental control system
EGT	Exhaust Gas Temperature
EMB 135	Embraer EMB-135
EMB 145	Embraer EMB-145
EPA	Environmental Protection Agency (USA)
ER	Engineering Releases
ESIS	European Chemical Substances Information System
EU	European Union
EU OSHA	European Agency for Safety and Health at Work

EWA	East West Airlines (former Australian airline)
FA	Flight Attendant
FAA	Federal Aviation Administration (USA)
FAAA	Flight Attendants Association of Australia
FAR	Federal Aviation Regulations
FDR	Flight data recorder, popularly known as a 'black box'
FID	Flame Ionisation Detection
FL	Flight Level (Aircraft Altitude)
FODCOM	Flight Operations Department Communication (UK CAA)
GC	Gas chromatography
GC/MS	Gas Chromatography separation followed by Mass Spectrometry
GCAQE	Global Cabin Air Quality Executive
GHS	Globally Harmonized System, Eu
GPWS	Ground Proximity Warning System
HE	High efficiency particulate air (filter)
HPLC	High pressure liquid chromatography
HSE	Health and Safety Executive (UK)
HSI	Horizontal Situation Indicator
HSW Act	Health and Safety at Work Act (1974), UK
HVAC	Heating, ventilation and air-conditioning
IAQ	Indoor air quality
IATA	International Air Transport Association
ICAO	International Civil Aviation Authority
ICAO	International Civil Aviation Organisation
IFALPA	International Federation of Airline Pilot Association
ILS	Instrument Landing System
IPA	Independent Pilots Association (UK)
IPF	Independent Pilots Federation (UK)

IRC	Industrial Relations Commission
ISM	Inspection Service Bulletin
ITF	International Transport Workers Federation
ITGAAQ	International Task Group on Aircraft Air Quality
JAA	Joint Aviation Authority
JAR	Joint Aviation Requirements
Jet Oil II	ExxonMobil Jet Oil II
LAME	Licensed Aircraft Maintenance Engineer
LF 502/507	Turbofan engine produced by Lycoming, AlliedSignal and then Honeywell Aerospace used on the Avro RJ update of the BAe 146
Mayday	International radio distress call
MCS	Multiple Chemical Sensitivity
MD 11	McDonnell Douglas (Now Boeing) MD11 (Newer version of the DC-10)
MD	Major Defect
MD80	McDonnell Douglas (Now Boeing) MD80
MEL	Minimum Equipment List
MJO	Mobil Jet Oil
MJO2	Mobil Jet Oil II
MMEL	Master Minimum Equipment List
MOCP	Mono-ortho-cresyl phosphate
MOR	Mandatory Occurrence Report (UK)
MOU	Memorandum of Understanding
MP	Member of Parliament
MRI	Magnetic Resonance Imaging
MRS	Magnetic Resonance Spectroscopy
MS	Mass Spectrometry
MSDB	Material Safety Data Bulletin
MSDS	Material Safety Data Sheet

NASA	National Aeronautics and Space Administration (USA)
NES	National exposure standard (Australia)
NICNAS	National Industrial Chemicals Notification and Assessment Scheme (Australia)
NIOSH	National Institute of Occupational Safety and Health (USA)
NJS	National Jet Systems (Australia)
NO_2	Nitrogen dioxide
NOHSC	National Occupational Health and Safety Commission (Australia, then ASCC, now Safe Work Australia)
NOTOP	Notice To Pilots
NOx	Oxides of nitrogen
NRC	National Research Council (US)
NTE	Neuropathy target esterase
NTP	National Toxicology Program
NTSB	National Transport Safety Board (US)
O_2	Oxygen
O_3	Ozone
OCP	Ortho-cresyl phosphate
OEL	Occupational Exposure Limit (UK)
OHRCA	Occupational Health Research Consortium in Aviation
OHS	Occupational Health and Safety
OP	Organophosphorus or Organophosphate
OPICN	Organophosphate Ester-Induced Chronic Neurotoxicity
OPIDN	Organophosphate Induced Delayed Neuropathy
OPIN	OP Information Network (UK)
OSHA	Occupational Health and Safety Administration (USA)
P1	Captain
P2	Co-Plot
P450	Cytochrome P450

PACK	Air Conditioning Pack
PALL	Pall Aerospace
PAN	Phenyl alpha naphthylamine or "PAN" an aviation radio distress call
PAX	Passenger(s)
PEL	Permissible Exposure Limit (USA)
PET	Positron Emission Tomography
PIC	Pilot in Command
PON 1	Paraoxonase
ppb	parts per billion
ppm	parts per million
PSA	Pacific Southwest Airlines
RAAF	Royal Australian Air Force
RJ	British Aerospace RJ (Newer BAe 146)
SAE	Society of Automotive Engineers
SAFE	Norwegian Union of Energy Workers
SB	Service Bulletin
SDRS	Service Difficulty Reports Search (US FAA)
SHE	Safety, Health and Environment
SHK	Swedish Accident Investigation Board (Swedish: Statens haverikommission)
SIL	Service Information Leaflet
SMAC	Spacecraft maximum Allowable Concentration
SNPL	Syndicat National des Pilotes de Ligne (France)
SRG	Safety Regulation Group (UK CAA)
STEL	Short Term Exposure Limit (ACGIH)
SVOC	Semi Volatile Organic Chemicals
TAP	Triaryl Phosphate
TBP	Tributyl phosphates

TCP	Tricresyl phosphate
TGWU	Transport and General Workers' Union
TLV	Threshold Limit Value (ACGIH)
TMCP	Tri-meta-cresyl phosphate
TMP	Trimethylol propane
TMPE	Trimethylol propane
TMPP	Trimethyl propane phosphate
TOCP	Tri ortho cresyl phosphate
TPCP	Tri-para-cresyl-phosphate
TPP	Triphenyl phosphate
TVOC	Total Volatile Organic Compounds
TWA	Time weighted Average
TWU	Transport Workers Union
USAF	United States Air Force
VOC	Volatile Organic Chemicals
WDR	German broadcaster
WHO	World Health Organisation

1.4 Abstract

This thesis examines the six-decade use of unfiltered aircraft bleed air, taken from jet engines to supply breathing air in the flight decks and passenger cabins of commercial and military transport aircraft. During this time numerous flight safety issues and adverse effects from exposure to contaminated bleed air have been reported. The research undertaken in this thesis investigated previous investigations into these matters and the consequences of using bleed air on flight safety and crew and passenger health. This research examined: (a) health issues reported by aircrew as a consequence of exposure to contaminated bleed air whilst flying by way of several descriptive surveys; (b) various aviation air monitoring studies previously undertaken were reviewed to assess the knowledge base of the chemicals present during contaminated air events; (c) air sampling data was evaluated for its usefulness in determining any potential adverse health effects; (d) a review was undertaken of the frequency of contaminated bleed air events; (e) a review was undertaken of some of the information known by the aviation industry and others about contaminated bleed air. Analysis of the evidence that bleed air, contaminated by synthetic jet engine oils and hydraulic fluids, is a regular and normal occurrence and far more common than previously accepted and is a consequence of the current bleed air system design. There are significant short and long-term health effects being reported as a direct result to documented exposure events that validate claims of adverse health effects in exposed individuals. The thesis argues that the precautionary principle, occupational health and safety guidelines and aviation regulations are being ignored by the aviation industry, who continue to claim that cabin air is safe. The systemic misuse of available data is widespread, secondary to commercial objectives, and places passenger and crew health and flight safety at serious risk. The thesis concludes that the use of bleed air on commercial aircraft with no form of contaminated air detection or filtration system present should be discontinued. The risk to health and flight safety is no longer acceptable.

2 Introduction

When the air supplied for passengers and crew to breathe onboard a commercial or military aircraft becomes contaminated with aircraft lubricants, such as synthetic jet engine oils, de-icing or hydraulic fluids, these events are known as *‘contaminated air’* events.

Contaminated air events primarily occur because all commercial jet aircraft built since the early 60s (with the exception of the Boeing 787 which first flew in December 2009), take air directly from the compression section of the engines (known as ‘bleed air’) and duct this air, after pressurisation and cooling, directly into the aircraft cabin unfiltered. When this air becomes contaminated with oils used to lubricate the engine or hydraulic fluids used in various aircraft systems, passengers and crew will be exposed. This design flaw introduced into military aircraft in the 1940s and commercial jet aircraft in the mid 1950s became universally introduced into all commercial jet aircraft manufactured from the early 1960s onwards.

Synthetic jet engine oils and hydraulic fluids contain a number of hazardous ingredients such as the organophosphates tricresyl phosphate and tributyl phosphate as well as the sensitiser N-phenyl-1-naphthylamine. The organophosphates which are neurotoxic and likely immunotoxic, are just some of the very large number chemicals present during a contaminated air event and which are released into the air supply when lubricating oils or hydraulic fluids are exposed to the extreme temperatures present in aircraft engines.

Contaminated air exposures occur in a hypoxic environment and may include a synergistic effect of exposure on passengers and crews, which can lead to additional adverse impacts on flight safety and or health.

The flight safety impacts of exposure result from the fact that:

1. no aircraft currently flying has any form of detection system fitted to warn crews when the air has become contaminated;

2. there is a lack of training and crew awareness of the adverse consequences of contaminated air exposures in the cockpit and cabin; and

3. crews are becoming impaired or incapacitated in flight as a direct consequence of these exposures.

The health effects of exposure can range from immediate, short or long term effects. Many of the short term health effects of exposure are accepted as occurring by many within the airline industry. However, all long term health effects as a consequence of exposure to contaminated air are denied by the airline industry.

How often exactly contaminated air exposures occur; and what the exact chemical makeup and concentrations of these chemicals are during such exposures is largely unknown. This lack of data is a consequence of 1) the fact no aircraft has any form of fitted detection systems fitted, 2) inappropriate monitoring of the air to date and 3) an ineffective reporting system. This lack of data and scientific knowledge is then cited by many within the aviation industry and some Governments, as an excuse not to act to prevent further exposures occurring, whilst ignoring volumes of data supporting the clear fact that contaminated air events are occurring, impacting flight safety and resulting in adverse health effects in many of those being exposed.

Limited studies have been carried out to investigate which chemicals are present in the aircraft environment but none effectively to date have successfully measured these contaminants during a contaminated air event. Despite this accepted knowledge gap, many in the aviation industry, including some Governments, advise that all chemical levels measured in aircraft cabins are below exposure standards recommended for working environments. These statements are made, whilst knowing they are unaware of what chemicals or concentrations are present in contaminated air events and also in the knowledge that exposure standards do not apply to workers working in hypoxic environments or to passengers or to the unique aviation environment these exposures occur in.

The military and commercial aviation industry has known of the risks of exposure to contaminated air for about sixty years, yet have failed to address the problem even though many accept that oil leaks do result in contaminated air events. Some limited aviation regulations exist and state what maximum amounts of a few chemicals, such as carbon monoxide, can be present in the aircraft; however, there is no system installed to monitor levels of these chemicals. Aircraft have cabin altimeters to show the cabin altitude of the aircraft but nothing to monitor the quality of the air being supplied. This is the air, on which all occupants of an aircraft depend on to survive in flight.

Scientific papers were published over five decades ago warning of the dangers of contaminated air exposure, yet commercial and vested interests have dealt with this clear design flaw by risking passenger and crew health in a manner previously seen with smoking, asbestos and other long fought battles of denial and corporate bias. Politicians have revealed how money has been paid for silence (for example, the confidential agreements between manufacturers and airlines tabled in the Australian Senate) and data has been falsified, in an effort to prevent crews and the travelling public from obtaining complete access to knowledge about this problem. Thus the genuine health and flight safety issues remain unaddressed at an industry wide level.

Oil and hydraulic products have almost exclusively only been tested as cold products in animal tests and have never been evaluated in the context in which exposure to these chemicals is occurring in flight i.e., exposure to the pyrolised product at reduced pressure via inhalation. The very limited 1950s inhalation testing data undertaken by the military that showed a serious problem did indeed occur when the oils were heated has been ignored. Despite the near total lack of testing data, agencies with the responsibility to do so, fail to ensure these products are properly evaluated or tested under actual exposure conditions.

Passengers are not advised when they are exposed to contaminated air and airlines are failing to comply with their duty of care to protect their employees and those that chose to fly with them. Airlines simply manage the situation by denial and marginalisation, in the knowledge that to date, health and safety agencies and aviation regulators, some of which are entirely funded by the industry they regulate, have failed to control and prevent exposures from occurring.

Only in time and with proper independent research will the full long term impact of contaminated air exposures be revealed.

2.1 Regulations and Standards

2.1.1 Overview

In order for an aircraft to be operated in a safe and airworthy manner, there are a broad range of guidelines and legislation that must be adhered to by all those within in the aviation industry. The origin of these guidelines dates back to a Chicago convention of 1944, that formed the International Civil Aviation Organisation (ICAO) to develop and promote the safe and orderly growth of international civil aviation throughout the world. [1] A range of protocols were developed by ICAO to which member countries are obliged to uphold through their own legislation, set down by each country's National Aviation Regulator such as the US Federal Aviation Administration (FAA), the Australian Civil Aviation Safety Authority (CASA) or the UK Civil Aviation Authority (CAA). This is done so that countries (signatory states) can follow an established set of guidelines, generally based on the US Federal Aviation Regulations (FARs) or European Aviation Safety Agency (EASA) Certification Specifications (CS) for Large Aeroplanes, formerly known as European Joint Aviation Regulations (JARs). This avoids countries spending considerable time and resources developing setting up new sets of regulations, and produces considerable international harmonisation. Thus, the aviation industry is a heavily regulated industry with clearly defined requirements set out in precise legislation to provide for the safe operation of commercial air transport.

These aviation regulations also clearly define that defects should be reported; the sort of data that should be collected; dictates that crews should not fly with any impairment; the aircraft must be airworthy to operate and so forth. Further, as well as national aviation regulations, there are also some national occupational health and safety guidelines to protect workers.

Most of the ICAO based guidelines and nationally adopted regulations relate specifically to the aircraft function. These are safety oriented and no part of the ICAO protocol requires member states to have any significant consideration for the health and comfort of air passengers apart from limited health issues such as medical first aid provisions or limits set for the pressurisation or ventilation of passenger cabins. [2]

Some argue that the regulations are not thorough enough with respect to potential crew exposure to contaminated air, [3] although there are regulations already in place which give limited detail and guidance. However these are not being adhered to. The failure to enforce many of these regulations is clearly linked to the chain of responsibility between the aviation regulatory authorities and the national or state health and safety regulators. The lack of clarity results in a failure to enforce regulations already in place.

2.1.2 Airworthiness Standards

The International Airworthiness standards for transport category aircraft detailed in part 25 of the FARs (JAR, EASA) are set down by ICAO. These detail what is required for an aircraft to be deemed *'fit for flight'* or *'airworthy.'* The airworthiness design standards cover many areas such as: aircraft design, aircraft performance, power plants, aircraft equipment, aircraft ventilation requirements and so forth.

2.1.2.1 Federal Aviation Regulations (FARs)

In the USA, the Air Commerce Act of 1926 saw the commencement of air transport regulations based on a series of Civil Aviation Regulations (CAR). In 1937, the first aviation regulation relating to fumes and carbon monoxide in the cabin or flight deck required that *'a suitable ventilation system shall be provided which will preclude the presence of fuel fumes and dangerous traces of carbon monoxide.* [4] In 1953, the US federal aircraft air quality regulations were expanded to include a requirement to provide *'a sufficient amount of fresh air to enable the crew members to perform their duties without undue discomfort or fatigue'*, noting that *'ventilating air in crew and passenger compartments shall be free of harmful or hazardous concentrations of gases or vapors*.' [5] In 1964, the airworthiness standard for aircraft ventilation was adapted under these newly created FARs. [6] In the case of aircraft ventilation the aircraft must be certified and continue to be maintained in service to continually comply with FAR 25.831 as shown in Figure 2-1

Figure 2-1: Excerpt of the 1964 FAR Ventilation Regulation 25.831

1964 FAR Sec. 25.831

Ventilation

(a) Each passenger and crew compartment must be ventilated, and each crew compartment must have enough fresh air (but not less than 10 cu. ft. per minute per crewmember) to enable crewmembers to perform their duties without undue discomfort or fatigue.

(b) Crew and passenger compartment air must be free from harmful or hazardous concentrations of gases or vapors. In meeting this requirement, the following apply:

(1) Carbon monoxide concentrations in excess of one part in 20,000 parts of air are considered hazardous. For test purposes, any acceptable carbon monoxide detection method may be used.

(2) Carbon dioxide in excess of three percent by volume (sea level equivalent) is considered hazardous in the case of crewmembers. Higher concentrations of carbon dioxide may be allowed in crew compartments if appropriate protective breathing equipment is available.

(c) There must be provisions made to ensure that the conditions prescribed in paragraph (b) of this section are met after reasonably probable failures or malfunctioning of the ventilating, heating, pressurization, or other systems and equipment.

(d) If accumulation of hazardous quantities of smoke in the cockpit area is reasonably probable, smoke evacuation must be readily accomplished, starting with full pressurization and without depressurizing beyond safe limits …

The US FAR 25.831 ventilation airworthiness standard was amended in 1996, [7] to include minimum outside ventilation to all occupants and to provide reasonable passenger comfort with a reduction in the carbon dioxide limit. However it only applies to aircraft initially certificated after 1997. The amended standard states that:

- *'Under normal operating conditions and in the event of any probable failure conditions of any system which would adversely affect the ventilating air, the ventilation system must be designed to provide a sufficient amount of* *uncontaminated air to enable the crewmembers to perform their duties without undue discomfort or fatigue and to provide reasonable passenger comfort...'*

2.1.2.2 EU Certification Standards (CS)

The US FAR regulations were the backbone for creating the similar European CS/JAR/EASA regulation 25.831. An extract is shown in Figure 2-2

Figure 2-2 Excerpt of the CS (EASA) Ventilation Regulation 25.831 - (Formerly JAR 25.831) [8]

VENTILATION AND HEATING

CS 25.831 Ventilation

(a) Each passenger and crew compartment must be ventilated and each crew compartment must have enough fresh air (but not less than 0.28 m^3/min. (10 cubic ft per minute) per crewmember) to enable crewmembers to perform their duties without undue discomfort or fatigue. (See AMC 25.831 (a).)

(b) Crew and passenger compartment air must be free from harmful or hazardous concentrations of gases or vapours. In meeting this requirement, the following apply:

(1) Carbon monoxide concentrations in excess of one part in 20 000 parts of air are considered hazardous. For test purposes, any acceptable carbon monoxide detection method may be used.

(2) Carbon dioxide concentration during flight must be shown not to exceed 0·5% by volume (sea level equivalent) in compartments normally occupied by passengers or crewmembers.

(c) There must be provisions made to ensure that the conditions prescribed in sub-paragraph (b) of this paragraph are met after reasonably probable failures or malfunctioning of the ventilating, heating, pressurisation or other systems and equipment. (See AMC 25.831 (c).)

2.1.2.3 Other

The USSR airworthiness regulations in 1985 listed that certain substances must not be above certain limits including: [9]

- vapours and aerosols of synthetic lubricating oils (2 mg/m^3);
- vapours and aerosols of mineral lubricating oils – (5 mg/m^3);
- CO (20 mg/m^3);
- formaldehyde (0.5 mg/ m^3), total aldehydes (0.6 mg/m^3);
- aromatic hydrocarbons(5 mg/m^3);
- nitrogen oxides (5 mg/m^3);
- fuel vapours (in terms of carbon) – (300 mg/m^3);
- ozone (0.1 – 0.2 mg/m^3) * Refer regulation for specific details.

Additionally the regulation stated that: [9]

- *‘At the joint presence of two or more substances of unidirectional biological effect in the cabin air, the sum of ratios of actual concentration values of each of them to their maximum admissible concentration values must not exceed 1. Presence of other harmful substances affecting the serviceability and health of the crew and passengers is not allowed.’*

In 2004 the Commonwealth of Independent States (Russian) airworthiness regulations were revised with Airwothiness Regulation 25.831a stating that a) ‘Under normal operating conditions and in the event of any probable failure conditions of any system which would adversely affect the ventilating air, the ventilation system must be designed to provide a sufficient amount of uncontaminated air to enable the crewmembers to perform their duties without undue discomfort or fatigue and to provide reasonable passenger comfort.’ [10]

The Russian Airworthiness Regulation 25.831b states *‘Crew and passenger compartment air must be free from harmful or hazardous concentrations of gases or vapors.’* The regulation specifically requires that in addition to CO and CO_2, when considering harmful and hazardous concentrations of gasses or vapours, the *‘Content of other toxic impurities must not exceed’* given values including: [10]

- TCP: 0.5 mg/m^3;
- Synthetic oil vapors and aerosols: 2 mg/m^3;
- Dioctyl sebacate: 5 mg/m^3;
- Acrolein: 0.2 mg/m^3; Formaldehyde: 0.5 mg/m$^{3;}$
- Nitrogen oxides: 5 mg/m^3; Benzol: 5 mg/m^3; Phenol: 0.3 mg/m^3;
- Fuel vapors: 300 mg/m^3; Mineral oil vapors: 5 mg/m^3 .

2.1.3 Continuing airworthiness

In order for an aircraft to be considered *'fit for flight'* it must at the time of its initial design certification; as well as on an ongoing basis which is termed *'continuing airworthiness'*, be maintained to the standard to which it is certified/designed. [11,12,13] ICAO refers to continuing airworthiness as:

- *'All of the processes ensuring that, at any time in its life, an aeroplane complies with the technical conditions fixed to the issue of the Certificate of Airworthiness and is in a condition for safe operation.'* [14]

While the airworthiness standards are listed as design standards, they are in fact in the FAA case also operating standards given the requirement (14 CFR 43.13 (b) and (c)) that any maintenance work *'be done in such a manner'* so as to restore the aircraft to its *'original or properly altered'* condition with regard to qualities affecting airworthiness. [3,15]

The EASA regulations state that:

- *'Continuing airworthiness means all of the processes ensuring that, at any time in its life, the aircraft complies with the airworthiness requirements in force and is in a condition for safe operation'* [16] No flight may take place unless the aircraft is maintained in an airworthy condition and any operational equipment fitted is correctly installed and serviceable or clearly identified as unserviceable. [16]

Also in 1964, the FAA issued an operating standard [17] stating that *'each passenger or crew compartment must be suitably ventilated'* and *'carbon monoxide concentration may not be more than [50 ppm], and fuel fumes may not be present'* (14 CFR 121.219). However, to date 46 years later, there are still no contaminated air detection systems fitted to aircraft to determine whether this requirement is met or not.

There are varying regulatory and Government responses with regard to the lack of detection systems to ensure the air meets the regulatory standards. These include:

- FAA: *'No present airplane design fulfils the intent of 25.831 because no airplane design incorporates an air contaminant monitoring system to ensure that the air provided to the occupants is free of hazardous contaminants.'* [18]
- UK Government: *'There are no statutory requirements for the fitting of air quality monitoring equipment in aircraft. Such equipment is not required because commercial aircraft ventilation systems are designed to supply air of an acceptable standard. This is confirmed at initial certification and, thereafter, each aircraft is subject to scheduled maintenance actions to ensure those standards are maintained. Air quality monitoring exercises have confirmed the acceptability of cabin air supplied. Where problems are encountered in service these are investigated and changes are introduced as necessary.'* [19,20]

While a growing number of authoritive bodies have recommended that detection systems be fitted to commercial aircraft [2,21,22,23,24,25,26,27] this has still not been accepted by any aviation regulator, even though the FAA has admitted no aircraft is airworthy without such systems.

While aircraft regulations globally allow an aircraft to operate with selected systems or part systems inoperative under the Minimum Equipment List (MEL) system, the MELs will never allow an aircraft to fly with an MEL, or a part or system inoperative, if the inoperative system or part is part of the airworthiness regulations. Such a case includes FAR/JAR/EASA 25.831, and as such defects falling into this area are required to be functional before further flight. The reason for this is that the airworthiness requirements such as the ventilation requirements of FAR/JAR/EASA 25.831 are safety related and must always be complied with for flight to take place. The MEL may not deviate from airworthiness requirements unless the airworthiness authority or the flight manual provides otherwise. [28]

The regulations clearly spell out the levels of carbon monoxide, carbon dioxide and ozone that are permissible, however, these fail to detail the levels of any other contaminants. These were essentially not considered when the legislation or its amendments were established as the intention was that there should not be any. Many in the industry including regulators, manufacturers and operators incorrectly assume that only the listed contaminants are covered. [29,30,31,32,33] However there is a requirement for the air to be free from harmful and hazardous concentrations of vapours and for the crew to operate without undue discomfort and fatigue and these two factors must be met for an aircraft to be able to fly. Examination of the various databases rather than incidents in isolation clearly show this is not occurring.

When questioned about the airworthiness in light of ongoing fume events, many are quick to say that the aircraft have been checked and meet all the certification requirements. [34,35,36] However, the regulations indeed show and as an example, the CAA clearly spelt out that an aircraft must continue to meet the original standards: [37]

- *'Throughout the life of an aircraft regulatory oversight seeks to ensure the continued airworthiness of that aircraft through approved maintenance practice and system modifications that are compatible with the original certification specification.'*

In contrast, BAe clearly only looked at CO, CO_2 [32] when certifying the aircraft as acknowledged by the Australian CASA officer who first certificated the BAe 146-300 series aircraft into Australia: [38]

- *'At the time of certification of the BAe 146 CASA only considered contaminated air in regard to contamination from carbon dioxide and carbon monoxide… even with a growing experience about cabin air problems, CASA seems to be reluctant to recognise any other contamination of the aircraft air system as being a certification problem due to a continued interpretation of the old clean air philosophy… The results flowing from the Australian Senate Committee into 'Air Safety and Cabin Air Quality in the*

BAe 146 Aircraft' illustrate the lack of awareness CASA had in regard to the 'Clean Air' problem and highlight the continuing airworthiness problems when the reporting scheme envisaged by the relevant aviation legislation is not followed.'

The lack of understanding of what is classified as harmful or hazardous and therefore the failure by the regulators to ensure the airworthiness regulation is met, has continued over many years. In 1999 CASA advised the determination of harmful or hazardous was a health standard and not its responsibility, while EASA ten years later advised harmful and hazardous were not defined and levels under the airworthiness regulation (CS 25.831) were not addressed. [29,39]

The CAA advised that *'It did not agree with the interpretation that events 'leading to discomfort' should be considered as a failure of JAR 25.831, unless there has been an adverse impact on 'safe flight and landing.'* [40] The regulator considered that the airworthiness ventilation regulations did not cover health and *'are limited in scope in addressing health effects, and are almost exclusively confined to assuring environmental conditions that would not incapacitate the persons on board due to short-term health effects and preclude safe flight and landing.'* [41] and *'Air contamination would be considered to make an aircraft unairworthy if it is likely to incapacitate the aircraft's flight crew.'* [42] Two legal opinions were obtained suggesting the CAA interpretation was wrong and all contaminants had to be covered and undue discomfort and fatigue indicated a breach of the requirements. [43] In contrast, EASA interpreted the legislation correctly when stating *'If there is a proven bleed air contamination (engine oils or hydraulic fluids) causing undue discomfort or fatigue, this does not meet 25.831.'* [44]

While the term *'undue discomfort'* may be interpreted subjectively, the presence of contaminants in airplane air sufficient to impair flight crew capability, or the ability of cabin crew to perform their duties effectively as expected under the legislation, would seem to be an apparent example of a breach of these regulations. [45] While the term *'harmful or hazardous levels of gases or vapours'* may also be subject to misinterpretation, especially in the use of measures of risk acceptability such as exposure standards, at least these offer the potential to clarify minimum sea level equivalences of what constitutes *'harmful'* or *'hazardous'* levels. Lack of or inadequate monitoring cannot imply there are no harmful or hazardous contaminants present if reports are consistently being made. [45]

2.1.4 Defects, defect and incident reporting

Another area set out in the ICAO protocols and adopted into national regulations covers the area of aircraft defects and the reporting of defects and occurrences. Airlines, crews, engineers and the regulators all have very clearly defined responsibilities in this arena.

In the Australian legislation an aircraft defect is considered to be an, *'imperfection that impairs the structure, composition or function of an object or system.'* [46] A *'Major Defect'* is, *'a defect of such a kind that it may affect the safety of the aircraft or cause the aircraft to become a danger to person or property.'* [46,47] Since 1992, CASA has advised that, '*smoke, toxic or noxious fumes inside the aircraft*' is a representative example of a major defect. [46] Before that time the Civil Aviation Orders in section 100.8 listed major defects as including, '*defects causing or likely to cause smoke or gas contamination of any part of the cabin, cockpit or baggage compartment.'* CASA withdrew Civil Aviation Order 100.8 in 1992. In New Zealand a similar pattern exists with both, '*Contamination of the cabin, cockpit, or baggage compartment'* and *'Smoke, or toxic or noxious fumes, in the aircraft'* required to be reported. [48]

There are various levels of reporting that differ only slightly internationally. In the Australian case, the pilot in command of the aircraft must report at the termination of each flight all defects that have come to his or her notice. [49] All defects are required to be entered on the aircraft maintenance release (technical log) and reported to the employer with a suitable investigation carried out. [50] Major Defects (MD) (except for those immediately reportable under CAR 51A) are required to be reported by the maintenance personnel to the holder of the certificate of registration and CASA within two working days containing the MD details and matters revealed by the investigation. [51]

Under European regulations the aircraft commander is required to ensure that all *'known or suspected'* technical defects occurring while he/she was responsible for the flight are recorded in the aeroplane's Technical Log. [52] The previous JAR equivalent legislation (JAR OPS 1.420) required that *'all technical defects'* be recorded in the aircraft log, rather than the stronger terminology used in the updated EASA legislation requiring *'suspected'* technical defects to also be recorded. Additionally the operator or commander of an aeroplane shall submit a report to the Authority (within 72 hours) of any incident that has endangered or could have endangered safe operation of a flight. [52]

Directive 2003/42/EC from the European Parliament and Council [53] set down a list of what incidents are considered reportable occurrences in civil aviation by member states. The list included incidents such as:

- Fire, explosion, smoke or toxic or noxious fumes;
- Incapacitation of any member of the flight crew or incapacitation of any member of the cabin crew which renders them unable to perform essential emergency duties;
- Occurrences which have or could have led to significant injury to passengers or crew but which are not considered reportable as an accident;
- An event leading to the declaration of an emergency or events requiring any use of emergency oxygen by any crew member;
- Use of any emergency equipment or prescribed emergency procedures in order to deal with a situation;
- Leakage of hydraulic fluids, fuel, oil or other fluids which resulted in a fire hazard or possible hazardous contamination of aircraft structure, systems or equipment, or risk to occupants;
- Any incident where any feature or inadequacy of the aircraft design could have led to an error of use that could contribute to a hazardous or catastrophic effect;
- Any other event which could endanger the aircraft, or affect the safety of the occupants of the aircraft, or people or property in the vicinity of the aircraft or on the ground;

- Repetitive instances of a specific type of occurrence which in isolation would not be considered reportable, but which due to the frequency with which they arise, form a potential hazard.

The European Directive was transposed into the UK Air Navigation Orders in August 2005. [54,55] Under CAP 393 the mandatory reporting of occurrences states that: *'This article shall apply to occurrences which endanger or which, if not corrected, would endanger an aircraft, its occupants or any other person'.* [55] The article defers to the European Directive by stating *'a list of examples of these occurrences is set out in Annexes I and II (and their Appendices) of Directive 2003/42 of the European Parliament and of the Council...'* [53]

The European directive [53] acknowledges that before an accident occurs, a number of incidents and numerous other deficiencies have shown the existence of safety hazards. Therefore, events such as those listed above are required to be reported in a mandatory reporting system by each member state, in order to gather data on such events so as to gain a better knowledge of these occurrences to facilitate analysis and trend monitoring in order to initiate corrective action. These reports are to be undertaken on a mandatory basis by the operator or captain of an aircraft, designers, manufacturers, maintenance organisations and so forth. [53] The UK ANR states, *'the sole objective of occurrence reporting is the prevention of accidents and incidents'* and requires the reportable occurrences to be advised to the CAA by similar people/organisations as set out in the European Directive. [55]

Up until mid 2005 the UK Air Navigation Regulations (ANR) of 1993 covered mandatory reporting and reportable occurrences relating to hazardous or potentially hazardous defects encountered during aircraft operations or maintenance. [56,57] The main difference was that the earlier ANR (pre 2005) required reporting of impairment to any member of the crew to undertake their required duties, rather than incapacitation only.

The CAA utilises the Mandatory Occurrence Reporting Scheme (CAP 382) to meet it's reporting obligations. [58] CAP 382 is an information and guidance document used to ensure safety information is utilised and disseminated along the same lines as set out in the European Directive and lists similar occurrences which should be reported. One notable difference was that before the change in

2005, toxic or noxious fumes were only required to be reported where emergency equipment or procedures were used. However, crews were not adhering to these procedures or the use of oxygen and the other reporting requirements would have necessitated a report anyway. CAA MOR reports to be submitted within 96 hours, clearly include, *'a defective condition or unsatisfactory behaviour or procedure which did not immediately endanger the aircraft, but which if allowed to continue uncorrected or which, if repeated in different, but likely, circumstances, would create a hazard.'* The MOR additionally states, *'Over enthusiastic reporting of such items which fall below this criteria will involve unnecessary duplication and work to both the reporters and the CAA and will also tend (by sheer volume of data generated) to obscure the more significant safety items.'* [58] All *'incidents relating to cabin air are amongst the examples of reportable occurrences.'* [54]

As an example of further reporting regulations, under the European system, in order to enforce continuing airworthiness, any person or organization responsible for continuing airworthiness, that is the aircraft is maintained in an airworthy state must report occurrences or defects in a variety of ways. [16,59] Such reports must be made to the state of registry, the organization responsible for the type design, and if applicable, the member state of operator, any identified condition of an aircraft or component that hazards seriously the flight safety. Where the maintenance organization is contracted by an owner or operator to carry out maintenance, it shall report (within 72 hours) any such condition effecting the aircraft or components, to the owner, operator or continuing airworthiness organization. [16,59] Any defect that hazards seriously the flight safety shall be rectified before further flight (M.A. 403) and any defect not rectified before flight shall be recorded in the (M.A 305) aircraft maintenance record system or (M.A. 306) operators technical log system as applicable. [16,59] Authorized certifying staff determine what defects seriously hazard flight safety and therefore which defects must be rectified before further flight and which defect rectifications can be deferred (M.A. 403). However this is not the case for defects approved under the MEL or defects determined as acceptable by the competent authority (M.A. 403). Continued flight safety is ensured by all relevant details known to the captain being recorded in the aircraft technical log including details of any failure, defect or malfunction affecting airworthiness or safe operation of the aircraft including those occuring in the galley or cabin or which affect the safety of the aircraft occupants. (AMC M.A. 306 (a)). [59]

Under the US system of reporting *'The pilot in command shall ensure that all mechanical irregularities occurring during flight time are entered in the maintenance log of the airplane at the end of that flig*ht time.' (14 CFR. 121.563) [60] Additionally each person who *'takes action in the case of a reported or observed failure or malfunction of an airframe, engine… or appliance that is critical to the safety of flight shall make, or have made, a record of that action in the airplane's maintenance log.'* (14 CFR 121.701) [61] There was however no requirement for crew or airlines to report to the FAA the '*accumulation of smoke or circulation of toxic or noxious gases in the crew compartment or passenger cabin'* until 1996, via the service difficulty reporting system (14 CFR 121.703), despite the concept of manufacturer's maintaining service difficulty reports for inspection for up to two years commencing back in 1965. [3,62,63] The FAA had been aware that *'fluid leaks or spills, e.g., hydraulic, glycol, etc., in combination with heat or ignition sources may produce hazardous quantities of smoke'* back in the mid 1980's. [64] While requiring airlines to report *accumulation of smoke or circulation of toxic or noxious gases* to the FAA from 1996, [62] the FAA 10 years later in 2006 described its *'growing concern over numerous reports of smoke/fumes in the cockpit/cabin'*, [65] noting *'numerous air carriers/operators who [sic] may not have reported these events as required by regulation'* and instructing its inspectors to improve airline compliance. [66]

Additionally the holder of a *'Type Certificate'* (manufacturer) for a particular type of aircraft or engine must report to the regulator certain types of defects or failures including the, *'accumulation or circulation of toxic or noxious gases in the crew compartment or passenger cabin.'* [67,68]

Despite having a rigorous reporting system in place, the system is not working, resulting in serious under-reporting and under-recognition of not only a safety issue but one that involves occupational health and safety as well. While there has been limited recognition of under-reporting by the FAA, this has not translated into action as in 2009, despite recognition that the reporting system was not working, the FAA advised it knew of 900 fume events in 10 years. [69]

The UK CAA has continued to insist it's reporting system is working satisfactorily, despite abundant evidence to show it is not and even allowed the UK COT committee to believe reporting fume events was not mandatory and accepted an airline's view that certain oil fumes did not need to be reported. [70,71,72] A similar example in an Australian case involved CASA in 2002 advising that an airline did not have to report cabin air contamination events prior to the issue of an airworthiness directive related to oil fumes. [73]

2.1.5 National Bureaus of Air Safety

Another area of defect and incident reporting globally that is under the ICAO reporting philosophy includes mandatory and voluntary reports made to the National Bureaus of Air Safety. An incident is an occurrence associated with the operation of an aircraft that affects or could affect the safety of the operation of the aircraft. ICAO and consequently most national investigation bureaus such as the UK Air Accident Investigation Branch (AAIB), US National Transport Safety Bureau (NTSB) and the Australian Air Transport Safety Bureau (ATSB) list events requiring the emergency use of oxygen by the flight crew or flight crew incapacitation, as serious incidents. [74]

National Bureaus of Air Safety have the option to investigate any incidents they choose to, but in reality very few contaminated air events appear to be investigated based on feedback from crews and the evidence reviewed. In Australia, similarly to the ICAO guidelines, [74] any case of smoke or fumes in any part of the aircraft; use of emergency oxygen by the crew or flight crew incapacitation; or the use of any emergency procedure (such as the use of oxygen due to aircraft fume contamination) is considered an Immediately Reportable Matter (IRM) to the ATSB. [75] A potential conflict of interest is related to under-reporting of fume events to the National Air Safety Bureaus due to incidents not being seen by the airline safety department or crewmember as reportable to their National Bureau. [76] For example, the Australian ATSB notes on its website that only *'a finite number of incidents will be investigated'*. In the UK the investigation of serious incidents along with accidents comes under the domain of the AAIB, however the choice remains with the Bureau as to which incidents will to be investigated. There are a few events publicly available for review on the German and Swiss Bureau of air accident websites and almost none on the NTSB.

2.1.6 Other regulations

There are ICAO airworthiness and design guidelines covering aircraft designs including, protection against the presence of smoke or toxic gases that could incapacitate the occupants of the aircraft. [77] Examples of other regulations to be considered under airworthiness specifications certification and the acceptable means of compliance demonstrating the suitability of engine bleed air (along with continued airworthiness requirements) are numerous with a few examples listed as follows:

- EASA, CS E 690 – Engine bleed: Suitability of compressor engine bleed air for direct use in the aircraft cabin pressurization or ventilation system requires contamination *'tests to determine the purity of the air supply.'* [78] An analysis of defects, which could affect the purity of the bleed air, must be prepared and where necessary the defects must be simulated and tests must be made to establish the degree of contamination which is likely to occur.
- EASA, CS E 510 – Safety Analysis: Analysis of the engine must show that hazardous engine effects are predicted to occur at a rate not in excess of that defined as *'extremely remote'* (probability of less than 10^{-7} per engine flight hour) including toxic products of engine bleed air. [79] Major engine effects must be predicted to occur at a rate not in excess of that defined as *'remote'* (probability of less than 10^{-5} per engine flight hour). [79] The safety analysis must include compressor bleed systems. Hazardous engine effects include *'concentration of toxic products in the engine bleed air sufficient to incapacitate crew or passengers'*…*no effective means to prevent flow of toxic products to crew or passenger compartments'* or *''degradation of oil leaking into the compressor air flow.'* Major engine effects include *'concentration of toxic products in the engine bleed air sufficient to degrade crew performance.'* [79]
- EASA, CS APU 210 – safety Analysis: The APU certification tests must likewise consider hazardous and major APU effects to the same degree of

probability. [80] Hazardous APU effects include *'concentration of toxic products in the APU bleed air for the cabin sufficient to incapacitate crew or passengers',* including *'degradation of oil leaking into the compressor air flow.* Major APU effects include *'concentration of toxic products in the APU bleed air for the cabin* sufficient to *'degrade crew performance.'* Again the APU safety analysis must include the compressor bleed systems. [80] For APUs, which provide compressor bleed air, the air intake duct must not release hazardous amounts of toxic gases into the bleed air. [81]

- FAA, FAR 25.1309: Aircraft systems and equipment *'must be designed to ensure that they perform their intended functions under any foreseeable operating conditions.'* [82] The regulation also requires that *'any failure condition which would prevent the continued safe flight and landing of the airplane is extremely improbable'* and *'any other failure conditions which would reduce the capability of the airplane or the ability of the crew to cope with adverse operating conditions is improbable.'*
- FAA, FAR 33.75 – Safety analysis: Failures that could result in major engine effects or hazardous engine effects must be analysed and determined to occur in the case of hazardous engine effects at a rate not in excess of being *'extremely remote'* (10^{-7} to 10^{-9} per engine flight hour) and with major engine effects, not in excess of *'remote'* probability of occuring (10^{-5} to 10^{-7}). [83] The analysis must include compressor bleed systems. *'Concentration of toxic products in the engine bleed air intended for the cabin sufficient to incapacitate crew or passengers'* is regarded as a hazardous engine effect. Any other effect falling between a straight partial or complete loss of engine thrust (and associated services) and hazardous engine effects is regarded as a major engine effect.

The lack of industry understanding relating to oil contaminants and regulatory requirements is well demonstrated by the UK AAIB in 2004 when referring to JAR (predecessor to EASA CS) APU-210; E-690 and E-510 recognizing that an unacceptable level of contamination must be extremely remote and is considered hazardous. [84,85] The AAIB then stated: [85]

- *'There are no regulatory certification requirements directly relating to engine and APU lubricating oils, with respect to ensuring as far as possible that they are free of any constituents that, potentially, could affect the occupants of aircraft should turbine engine oil leak into the bleed air system.'*

A unique perspective on how the industry views contaminated bleed air can be found with an FAA explanation that *'JAR-E includes a unique hazard, 'toxic bleed air'.'* [86]

Interestingly, the former 1976 British Civil Aviation Airworthiness requirements which were superseded by the JAR airworthiness regulations in 1979 were very specific, stating that no failure of components in the air supply system, the probability of occurrence assessed as being greater than *'extremely remote'* shall result in a hazardous effect; no failure assessed as *'recurrent or remote'* shall result in leakage into the air supply which would hazard the aeroplane or its occupants and that dangerous concentrations of harmful substances cannot occur in occupied compartments. [87] The regulation specifically states:

- *'in normal operation or after a failure in the power plant, it shall be shown that dangerous concentrations of harmful substances cannot occur in occupied compartments e.g. where the cabin air supply is obtained from a direct tapping on a turbine engine.'* and *'no materials which give off noxious fumes when heated shall be used in such a way that they may become heated in normal or failure conditions to the extent that the cabin air would become dangerously contaminated.'* [87]

Although similar regulations will exist in every country there are additional aviation specific regulations that are (indirectly) linked to contaminated air exposures. Examples of these in Australia are:

- *Flight not to commence until the captain is sure the required operating crew are on board and in a fit state to perform their duties and the aircraft is safe for flight in all respects. (CAR 233)*

- *Operating crew members are not to act as pilots etc. if in a state such that his/her capacity to act as required is impaired by having absorbed any substance (CAR 256) and must not act as authorised flight crew while his or* *her ability to do the act efficiently is, or is likely to be, impaired to any extent by an illness or injury, no matter how minor. (CAR 6.16A)*

- *A pilot shall not fly and an operator shall not require the pilot to fly if either the flight crew member is suffering from, or considering the circumstances of the particular flight to be undertaken, is likely to suffer from, fatigue or illness which may effect judgment or performance to the extent that safety may be impaired. (CAO 48.0)*
- *Maintenance Release ceases to be in force if the aircraft has developed a major defect (other than defect permissible under the MEL system) and the aircraft is to be flown before the major defect has been remedied. (CAR 47)*

In 2007, the ICAO council was requested to review ICAO Standards and Recommended Practices (SARPs) for the protection of aircraft passengers and support further research on the consequences of air travel on the health of crew and passengers. [88] As such ICAO passed Resolution A35-12 on the protection of health of passengers and crew in commercial aircraft, which states:

- *'The protection of the health of passengers and crews on international flights is an integral element of safe air travel and that conditions should be in place to ensure its preservation in a timely and cost-effective manner.'*

Importantly, the EU established the Precautionary Principle, which should be applied. [89]

- *'Recourse to the precautionary principle presupposes that potentially dangerous effects deriving from a phenomenon, product or process have been identified, and that scientific evaluation does not allow the risk to be determined with sufficient certainty.'*
- *'Recourse to the precautionary principle presupposes:*
    - *Identification of potentially negative effects as a result of a phenomenon, a product or a process;*
    - *A scientific evaluation of the risk which because of the insufficiency of the data, their inconclusive or imprecise nature, makes it impossible to determine with sufficient certainty the risk in question.'*

2.1.7 Occupational Health and Safety Regulations and Guidelines

In addition to the aviation regulations, there are also Occupational Health and Safety (OHS) regulations and guidelines in most countries to protect workers in the workplace in a variety of ways. These are administered by bodies such as the UK Health and Safety Executive (HSE); the Australian National Occupational Health and Safety Commission (NOHSC) or the various State and Territory WorkCovers; the European Agency for Safety and Health at Work (EU-OSHA) and the US Occupational Health and Safety Administration (OSHA). The current state of play in Australia, US and UK workplaces in regards to these regulations and guidelines is important to investigate to better understand how the aviation industry and the relevant national health and safety regulators play one off against the other, resulting in crews and passengers not being adequately protected from contaminated air.

Australia will be used as an example of what standards and guidelines are available. In Australia there are two levels of regulations, *'guidelines'* or *'standards'* to protect the worker in the workplace. The individual various states and territory Governments have responsibility for enacting laws under their individual Occupational Health and Safety Acts to ensure workplaces are safe and healthy. It is the (former) National Occupational Health and Safety Commission (NOHSC) (now Safe Work Australia) that provides a set of National OHS standards and codes of practices. These standards and codes cover areas such as: hazard identification process, risk assessment, control, monitoring and review in the workplace; employee training and supervision in the workplace; provision of appropriate information; consultation with employees and their health and safety representatives for those likely to be exposed to risks; health surveillance; record keeping and employee responsibilities. A few of the standards and codes include: [90]

- National Model Regulations for the Control of Workplace Hazardous Substances (1994); [91]
- National Code of Practice for the Control of Workplace Hazardous Substances (1994); [92]
- National Standard: List of Designated Hazardous Substances (1999); [93]

- National Standard: Approved Criteria for Classifying Hazardous Substances (2004); [94]
- National Standard: Exposure Standards for Atmospheric Contaminants in the Occupational Environment (1995); [95]
- These last three national standards were replaced by the computer-based Hazardous Substances Information System (HSIS) in 2005. [96] The standards are still available on the Safe Work Australia system without amendments.
- Guidance Note for the Guidance Note on the Interpretation of Exposure Standards for Atmospheric Contaminants in the Occupational Environment (1995); [97]
- National Code of Practice for the Preparation of Material Safety Data Sheets (2003); [98]
- National Code of Practice for the Labelling of Workplace Substances (2003); [99]
- Guidance Note for the Assessment of Health Risks Arising from the Use of Hazardous Substances in the Workplace (1994). [100]

Of interest is the National Model regulations for the control of Workplace Hazardous substances [NOHSC 1005(1994)] which state that, '*An employer shall ensure that a suitable and sufficient assessment is made of the risks to health created by work involving potential exposure to any hazardous substance.'*

Importantly the basis for determining if a substance is hazardous or not is the approved criteria for classifying hazardous substances, [94] which are adopted from European Community's (EC) legislation for classifying dangerous substances. [101] The criteria are taken from the EC Council Directive 67/548/EEC and Directive 1999/45/EC and subsequent updates. [102,103] The European Chemical Substances Information System (ESIS) is the European Internet hazardous substances database upon which many others are modelled internationally, such as the Australian HSIS. [104] In 2009 Regulation (EC) No 1272/2008 [105] on on classification, labelling and packaging of substances and mixtures was introduced, implementing the Globally harmonised System (GHS). The new legislation will *'will stepwise replace Directive 67/548/EEC (substances) and Directive 1999/45/EC (preparations)'* over the period December 2010 to mid 2015. [106]

In the United Kingdom, the Health and Safety at Work (HSW) Act 1974 established the Health and Safety Commission (HSC) and the Health and Safety Executive (HSE). They are responsible for making arrangements to secure the health and safety of people at work and of the general public. In order to avoid duplication of activities of either regulatory body, a Memorandum of Understanding (MOU) was established between the CAA and HSE exempting aircraft from many of the regulations. [2,107] Therefore the HSE had *'no active responsibilities in relation to the health of airline passengers or crew'* and the CAA was stated to have *'Its prime responsibilities for passengers are to regulate for their safety. It has no direct responsibilities for passenger health or comfort.'* [2]

In 2006 the Civil Aviation Act was amended giving the CAA responsibility to safeguard the health of (all) *'persons on board aircraft.'* [108] Civil Aviation (Working Time) Regulations were adopted in 2004 requiring employers to ensure each crewmember is at all times provided with *'adequate health and safety protection and prevention services or facilities'* appropriate to the nature of the work. [109,110] Effectively under the MOU, the HSE retains enforcement responsibilities for employee/employer consultation legislation, while the CAA is given OHS enforcement responsibilities under the Civil Aviation Regulations 2004. [109,111] With specific regard to exposures to hazardous substances within aircraft, the CAA was given responsibility for (UK registered or certified aircraft) *'the effect of substances on ability of crewmembers to operate the aircraft, safe flight and landing.'* The CAA Aviation Health Unit (AHU) was charged with giving (UK registered aircraft) *'advice to Government on the possible health implications of exposure to hazardous substances to crew and passengers.'* CAA Aviation OHS was charged with ensuring (UK registered aircraft) *'risks to OHS to crew members from exposure to hazardous substances are being adequately controlled on board aircraft.'* The HSE was given responsibility for adequately controlling risks to OHS of non crew members and crew members on the ground outside the aircraft. [111] Therefore the *'HSE will lead on occupational health and safety issues affecting employers, employees (except crew members on board the aircraft) the self-employed, and passengers during such time as the aircraft is on the ground with the doors open, or the aircraft is manoeuvring or being manoeuvred on the ground without the intention of flight.'* [111] The HSW Act 1974 in relation to aircraft, provides for the HSE being *'the enforcing authority for work activities at factories making and repairing aircraft, fuel depots, and most work activities at airports'.* However, [110] the HSW Act 1974 *'applies to aircraft in flight or on the ground'* around GB. [111]

Additionally the *'HSE will raise with the CAA concerns if they believe that an aircraft or its operation poses risks to the occupational health and safety of crew or passengers on board whilst it is in flight within GB airspace.'* [111]

Under the MoU the HSE (apart from consultation arrangements) do not enforce health and safety legislation in relation to crew members (flight and cabin crew) of UK operators when on board the aircraft. [112] The Civil Aviation (Working Time) regulations 2004 enforced by the CAA apply a general health and safety duty for the protection of crew members of UK operated aircraft while on the aircraft. [112] This legislation *'does not directly mirror the Health and Safety at Work etc Act 1974 and associated legislation.'* The CAA draws upon *'existing good practice including HSE standards and guidance and adapted it to the aircraft environment. This guidance can be found in CAA publication CAP757.'* [112] However, the 2005 CAP 757 failed to mention any form of toxic hazard or contamination, whilst the 2010 version lists *'poor maintenance of ventilation and filtration systems'* under the heading *'bio hazards'.* [113] Operators are advised to *'make suitable and sufficient assessment of the risks from biohazards in the cabin environment'* and *'where this risk assessment indicates significant risks to crew members, control measures should be implemented to reduce that risk as far as is reasonably practicable.'* [113] There is no mention otherwise of contaminated air exposures.

The CAA's primary powers and duties are focused on the safe operation of aircraft. This aviation safety activity will take primacy over CAA's occupational safety and health considerations and responsibilities. [110]

However the practical realities are that despite the fact that the Control of Substances Hazardous to Health (COSHH) regulations do apply to aircrew [114] and the HSW Act applies to aircraft in flight or on the ground (in UK), [111] the CAA do not enforce COSHH or HSW Act in aircraft for crew. [115,116] The HSE will raise concerns with the CAA if they believe an aircraft poses risks to the OHS of crew or passengers in flight over British airspace. [111] The CAA has *'no authority'* to enforce the COSHH (HSW Act) regulations with *'enforcement duties falling to the HSE… it is therefore inappropriate for the CAA to investigate any alleged breaches of the COSHH regulations' w*ith the MOU setting out the division of roles. [116] Therefore aircrew except when on the ground outside the aircraft are removed from having access to HSE expertise, policies and procedures. This is despite the fact that the HSW Act 1974 places general duties on employers to *'look after the health, safety and welfare of their employees and members of the public who may be affected by the work activity'.* [110] Under the act employers are required to *'undertake a risk assessment to assess the risk to workers and anyone else, including members of the public, who may be affected by the work activities being undertaken.'* [110]

There is a similar dilemma in the US. In 1975 the FAA took responsibility as a result of the 1971 newly established Occupational Safety and Health (OSH) Act. The FAA assumed *'complete and exclusive responsibility'* of crewmember safety and health on aircraft in operation Under Section 4(b)(1) of the OSH Act, which allows a US agency with expertise in a given industry to regulate its own workers. [117,118] The basic protections established and enforced by the US Occupational Safety and Health Administration (OSHA) under the OSHA Act do not apply to crewmembers, however, the FAA has not published occupational health and safety protections for air quality-related hazards. [119]

The reality is that there is a major conflict occurring between the occupational health and flight safety regulatory arenas, with the end result being that neither is effectively enforced. While the UK and US are examples of states where OHS powers are given to the aviation regulator, which in practice fails to enforce the available legislation, the Australian scenario gives workers OHS NOHSC protection, which has failed to be efficiently utlised by the state powers. There has been an ongoing dispute between aviation regulators, manufacturers and airlines stating that the contaminated air issue is an occupational health and safety issue, rather than a flight safety issue and one that is outside their expertise and should be left to the relavant OHS regulatory authority. [45,120,121,122,123,124,125,126] The paradox between the aviation and OHS regulator's can be summed up well in the following quotes:

Aviation regulator: *'When you start talking about the general subject of toxins in atmospheres, and specifically in this case in the atmosphere within an aircraft, then it is outside CASA's area of expertise. We are responsible for aviation safety. I think we are now getting into occupational health and safety issues which I think you need an expert in occupational health and safety to consider rather than an aviation safety authority.'* [121]

OHS Regulator: *'Worksafe… is unable to pursue this matter further due to the complexities of the issue (which somewhat exceed WorkSafe's expertise)… May I suggest that you direct any further enquiries to CASA as the lead agency regarding this matter.'* [127]

The FAA was little different when suggesting exposure to contaminated air does not address *'an immediate safety concern.'* [3,128] The airlines view on their OHS responsibilities towards contaminated air generally echoes that of the FAA. As an example a pilot union report stated: *'British Airways Health Services (BAHS) advise flight ops that there is no long-term health risk associated with CAQ (cabin air quality) events, and as a result BA have not carried out risk assessments on cabin air quality.'* [129] Representatives of the airline when asked about risk assessments advised they did not have to be done and had not been done as there were no hazardous substances in the air to which crew or passengers had been exposed and therefore there was nothing to assess and similar. [130,131]

CASA despite ongoing denial that contaminated air fell under their responsibility and despite regulations dating back many years showing contaminated air was considered a major defect, finally in 2004 acknowledged *'All instances of smoke or fumes in the aircraft cabin that adversely affect the quality of cabin air on Australian registered aircraft operating domestically or internationally, are categorized by the Civil Aviation Safety Authority as a Major Defect.'* [132] The regulatory link between flight safety and occupational health and safety was recognised by the Australian Senate when recognizing that the aviation regulations required pilots (crew) to be in a suitable state of health to operate an aircraft. [21]

2.1.8 To Summarise

There is a direct conflict of interest being seen in the aviation industry which can be summed up with regulator's effective denial of responsibility for a variety of reasons which include the following:

- *'We don't regard fumes as an immediate threat to aviation safety. Obviously if we did we would have to ground flights.'* [133]
- *'It was noted that CAA activities were funded by full cost recovery from industry.'* [37]

As far as the aviation regulatory authorities go, there are assortments of views that amount to the same thing. Crew health and safety issues connected with air supply contamination are not being treated as their responsibility. The question of who was responsible for health and safety issues in respect of aircraft (contaminated air) was raised some years back with neither regulatory body seemingly doing its job. [134] This has now been semi resolved, however the system is still not working with the available legislation being effectively ignored and the aviation industry hiding behind the need for further research instead of protecting crew and passenger health and safety. A limited number of regulators have in recent years taken some actions to address this issue (as will be seen via this thesis), however the various health and safety executives have effectively remained uninvolved in addressing cabin air contamination, Regulations do exist to protect crew and passenger health and safety with regard to contaminated air; however these are seen by many as not specific enough. [76] Aviation regulators must have and utilise powers to monitor and take enforcement action against operators that fail to implement internationally recognised protection measures that prevent passengers and crew from aircraft fume exposures.

2.2 Aircraft Air Supply

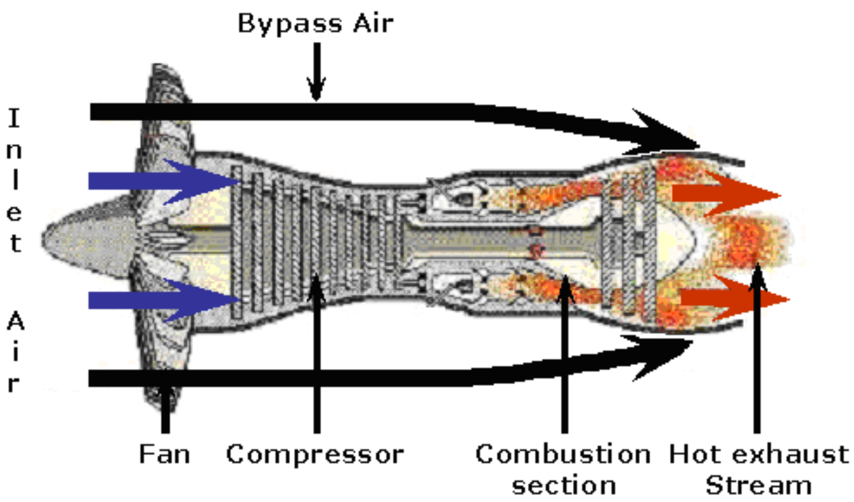
2.2.1 Introduction

To enable passengers and crews to live in a reduced pressure environment in flight, with outside temperatures in the -60°C region, they are provided with a life support system known as a pressurised cabin. The aircraft is pressurised so that when a commercial jet aircraft attains its maximum designed cruising altitude, the cabin altitude or the equivalent altitude if on the ground, would be about 8000 feet (2438m).

2.2.2 Bleed Air

Currently pressurising the aircraft and providing an air supply to the passenger cabin and cockpit, is achieved by taking *'bleed air'* from within the engine and feeding this into an Environmental Control System (ECS). Figure 2-3 shows the cutaway diagram of a jet engine. This is a view looking sideways at the engine. The *'Inlet Air'* from the atmosphere is the outside air and as it enters into the engine it either bypasses the core or centre part of the engine, in which case it is known as *'Fan Air'* or *'Bypass Air'*; or it enters the core of the engine where the air is compressed within the compression section of the engine before entering the combustion section of the engine. In the combustion section jet fuel is added to the compressed air which accelerates out of the back of the engine as hot fast moving air.

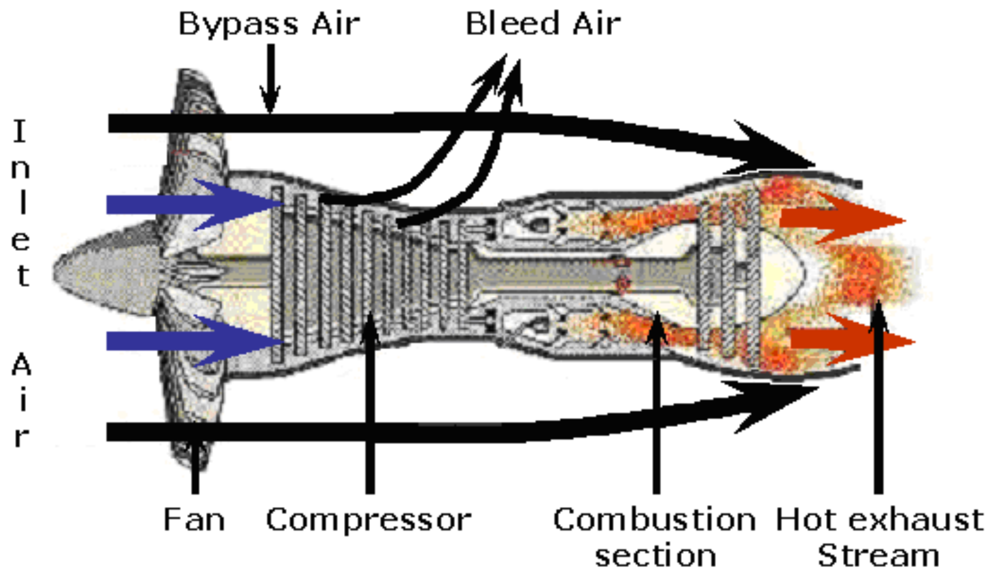
Figure 2-3: Schematic of the air flow in a modern jet engine



The exhaust air also drives several turbines which turn the compression and fan sections of the engine. Typically, about 75% of the thrust of a normal bypass gas turbine engine is produced from the main front fan of the engine. The other 25% is produced from the exhaust gases.

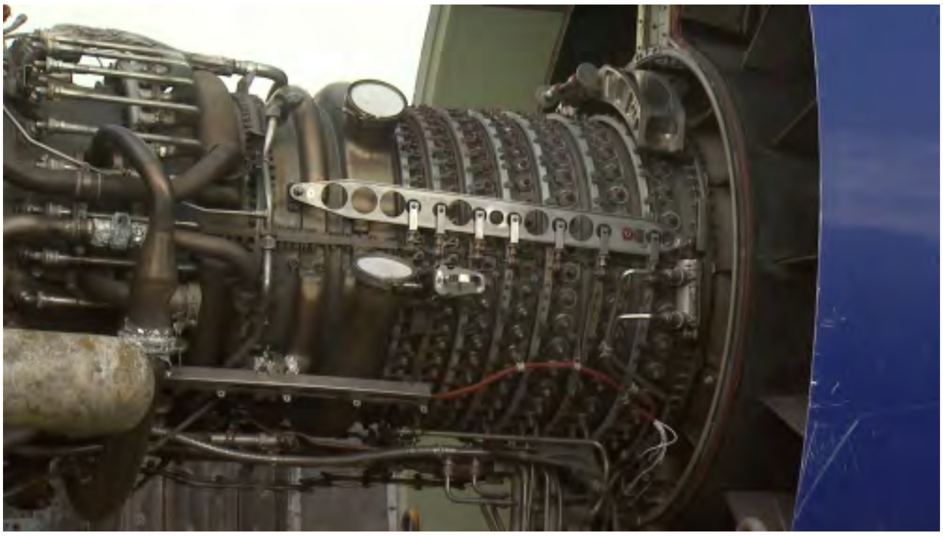
The majority of the air entering the core of the engine passes on to the combustion section but some of the compressed air, typically 2-8%, [135] is *'bled off'* as *'bleed air'* which can be taken from specific compression stages of the compressor section of the engine as designed by the engine manufacturer. The location of the bleed air port(s) on the engine will be dependent on the pressure or temperature required for a particular task or stage of flight. Engines are usually designed with a low and high stage pressure bleed air take off point within the compression section of the engine because as thrust increases the pressure within the compression (and temperature) section of the engine also increases. Therefore, at high power settings the bleed air will normally be taken from the lower pressure take off point reverting back to the high pressure take off point when the pressure at the low pressure point decreases below a predetermined level. Bleed air is normally extracted from the low stage compressor port, however when engine power is below the level at which the low stage meets the *'using systems needs'*, the high pressure stage is then utilized. [136] At low engine power settings, the high stage air is the only source of air sufficient to meet the needs of the bleed system. [137] That is, the high stage port is required when the air coming off the low/intermediate stage is not adequate, or a considerable amount of air is necessary and the engine is being operated in conditions that cannot be deteriorated by intensive air bleeding, typically during taxiing, take off and descent with the engine near idle. [135] Bleed air is extracted at the lowest practical temperature/pressure to meet system needs (aircraft pneumatic services) at best economy, whilst limiting the temperatures to which the air is heated by using (in most cases) the multi stage bleed extraction system. [137,138] The use of the low stage air is used to the maximum extent possible with it's inherent savings in aircraft performance penalty encountered with use of higher stage air. [138] The air which is *'bled off'* from the engine is done so before the compressed air enters the combustion section of the engine as shown in Figure 2-4.

Figure 2-4: Schematic of the generic locations of engine bleed air



The design of the bleed air system for cabin air is different for different engine and APU types. [139] In some constructions the air is extracted far forward on the engine where the compressor air is not so hot and where oil leakage from a bearing casing may or cannot end up in the bleed air system. [139] In other engine constructions, the air is extracted farther back in the compressor *'where both pressure and temperature are higher and the risk of leaking oil possibly finding it's way out via the bleed air is greater.'* [139] The engine used on the BAe 146 (ALF 502/507) takes the air from a single (does not use low and high stage ports) output of the HP compressor located (ring formed duct) on the combustion case shroud aft of the compressors. On most modern jet engines, the bleed air outlet is located farther forward on the engine, i.e. somewhere on the compressor section of the gas generator. [139] Additionally on most jet engines the air is bled from the intermediate (IP) or low stage (LP) compressor stages in addition to the high stage (HP) at certain engine operations. Depending on the thrust settings of the engine in question, the temperature of the bleed air will vary. A bleed air port can be clearly seen in Figure 2-5.

Figure 2-5: Bleed air ports on high bypass gas turbine engine



When the bleed air leaves the compression section of the engine it is very hot. Temperatures reported in the high stage compression section of an engine can be in the region of 300 to 650°C, yet in the intermediate (low stage) compressor they will be considerably lower between 50 and 300°C. [140] The bleed air used on the BAe 146 is said to range between 100 and 400°C. [139] Therefore, the air must be cooled before entering the passenger cabin or cockpit. Cooling is done usually initially by a heat exchanger such as a *'pre-cooler'* which are located in the engine struts cooling the air down to around 200°C and then, after flowing through ducting in the wing, enters the *'Air Conditioning Packs'* or 'A/C *pack.'* [141]

A typical Rolls Royce RB211-535 series jet engine as used on the Boeing 757 has a single-stage wide-chord fan at the front of the engine, six Intermediate Pressure (IP) compressor stages and a further six High Pressure (HP) compressor stages. The BAe 146 ALF 502/507 engine is unusual in that it only uses uses a single air bleed extraction system utilizing a portion of high pressure air from the high pressure compressor.

The term *'Air Conditioning Pack'* in fact relates only to the conditioning of the air temperature and humidity and not to actual air quality as any contaminants present in the bleed air will not be removed by the *'pack'*. The *'pack'* is usually an air cycle machine (ACM) turbo compressor/expansion turbine cooling device. The ACM lowers the excessive engine compressor bleed air temperature to a reasonable temperature for cabin and flight deck use. The cooled air then flows to a chamber where it is mixed with an approximately equal amount of recirculated air from the passenger cabin. The combined outside and filtered air is ducted to the cabin and distributed through overhead outlets located in the passenger cabin.

Inside the cabin, the air flows in a circular pattern and exits through floor grilles usually located on either side of the cabin or, on some airplanes, through overhead intakes. The exiting air is then exhausted from the aircraft through an outflow valve which also controls the cabin pressure.

Bleed air as well as being used for the aircraft ECS can also be used for various other functions if incorporated into a particular aircraft design. Other uses include engine anti-icing to warm the front part of the engine cowling to prevent ice build up, to drive the leading edge flap drive motors, air driven hydraulic pumps, cargo heat and so forth.

2.2.3 Bleed Air Origins

The US military is thought to have been the first to use air drawn in through the engine compressor for conditioning purposes for the Douglas XB-43, Lockheed P-80 and Convair P-81 in 1944/1945. [142] The first commercial aircraft to use bleed air to supply cabin air directly from the engines, as is now common place throughout the aviation industry was the SE 210 Sud Caravelle manufactured in France in 1955 (see Figure 2-6).

However the vast majority of early jet airliners such as the DeHaviland Comet, Boeing 707, McDonnell Douglas DC8 and Vickers VC-10 did not use bleed engine air directly into the aircraft cabin but used the bleed air to indirectly drive a separate blower/compressor which itself would introduce outside air into the passenger cabin.

Engines were less efficient in the early days of jet engined commercial airliners than they are today. As a consequence there were considerable concerns about the air being contaminated (refer chapter 6 of this thesis) if they allowed the bleed air to supply directly into the aircraft cabin. In fact the Convair 990 jet, which in its time was the worlds fastest commercial passenger jet aircraft and which was built to compete with the Boeing 707 and DC8, had the infrastructure to allow the bleed air to directly enter the aircraft cabin, rather than to drive the compressor/blowers it used, but this was for emergency *‘alternate pressurisation’* use only. [143]

Figure 2-6: SE 210 Sud Caravelle

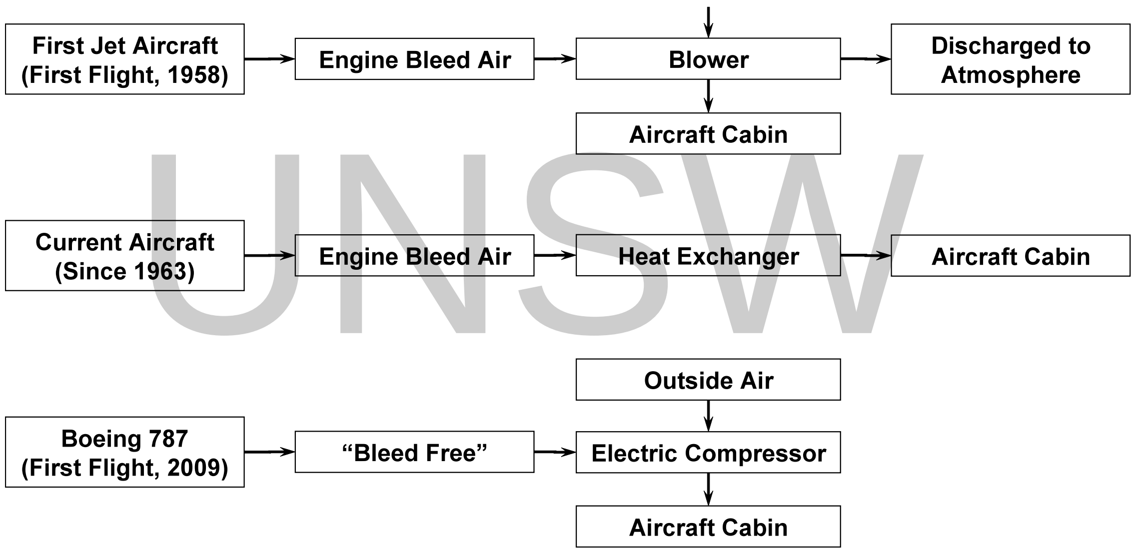
A 2005 aviation industry SAE statement describes the concerns quite well (apart from the view on frequency in today’s aircraft) when stating: *‘Improved seal design. First-generation jetliner engine bleed air was contaminated with lubricating oil to the degree that turbo-compressors were necessary to provide the cabin air. Turbine lubrication seals have been improved such that concentrations of lubricating oil in bleed air is negligible.’* [33]

The direct introduction of bleed air directly into the passenger cabin became widely used around about the time of the Boeing 727 and 737 which first flew in 1963 and 1967 respectively. By changing to the current bleed air system design, aircraft engine bleed air demands have been decreased which has provided considerable reduction in fuel consumption. Greater efficiency, less mechanical weight and lower fuel costs are benefits of introducing unfiltered bleed air directly into the aircraft cabin. The Vickers VC-10 became the last commercial jet aircraft designed not to directly introduce bleed air into the aircraft when it flew in 1962.

The difference between the use of bleed air to supply the passenger cabin and cockpit directly, compared to the use of the bleed air to operate compressors and blowers, which independently provided outside air necessary for the aircraft is shown in Figure 2-7.

While all the air from the engines of early turbojet aircraft went through the core, fuel consumption was very high, however the additional fuel required to provide outside air to the cabin was very small as the bleed air extraction was a small percentage of the total core airflow. [137] Turbofans were then developed using initially core bypass ratios of around 2 to 1, which improved fuel economy and the cost of engine bleed air relative to overall fuel consumption was still relatively small to make using 100% bleed air direct into the cabin cost effective. Lower direct fuel costs and shorter sector lengths also played a role here. As higher bypass ratios engines were developed, fuel consumption to provide engine thrust reduced, however the fuel consumption to extract bleed air increased *'dramatically'.* [137]

Figure 2-7: Bleed Air Path



2.2.4 Early awareness of contaminated air

There was an awareness of contaminated air as early as 1937 when the US Bureau of Air Commerce published regulations that required *'a suitable ventilation system shall be provided which will preclude the presence of fuel fumes and dangerous traces of carbon monoxide.'* [4] In 1953, an aviation toxicology textbook stated that smoke formed by lubricating oil contacting hot surfaces can contain *'irritant and toxic aldehydes and other dangerously toxic products of incomplete combustion.'* [144] That same year the US Federal aircraft air quality regulations were expanded including a requirement to provide *‘a sufficient amount of fresh air to enable the crew members to perform their duties without undue discomfort or fatigue’*. [5]

There was an additional requirement that *‘ventilating air in crew and passenger compartments shall be free of harmful or hazardous concentrations of gases or vapors’,* with *‘Harmful or hazardous concentrations’* being defined in terms of carbon monoxide (CO) and carbon dioxide (CO2). References to harmful or hazardous concentrations of gases or vapors and undue discomfort or fatigue were removed in 1954, but reinstated in 1964 along with limits on CO and requirements that fuel fumes were not present. [6] This coincides with the move towards using bleed air from the engines directly for the cabin air supply. In the early 1950s there was awareness that synthetic lubricants required for newer engines operating at higher temperatures would lead to thermal degradation and possible toxicity consequences. [145] In 1954 both the military and the aviation industry were aware of the need for toxicological information involving the thermal decomposition of lubricants and hydraulic fluids with tests subsequently undertaken. [146,147] Further contaminated air reports (until this thesis examination - refer to chapter 6) have not been readily publicly available but limited manufacturer concerns can be sourced [148] and smells *‘characteristic of synthetic jet oils’* were reported *‘not infrequently’.* [149] It is also very likely that contaminated air smells were partially masked until the 1990s by smoking on aircraft, which was only banned on commercial aircraft in late 1980s and early 1990s around the world. [150,151]

2.2.5 Sources of contamination

Contaminants and sources of contamination to be considered in the design, operation and maintenance of aircraft environmental control systems include; deicing fluid, engine oil, hydraulic fluid, exhaust fumes, fuel, ozone, bacteria and viruses, pesticides, lavatory fluids/odours, cargo/carry on baggage, anti corrosion spray/paint, galley odours, solvents, electrical odours and dry ice. [24,33,152] Synthetic lubricants, hydraulic and deicing fluids are the subject of this thesis. *‘Aircraft fluids such as engine oil, hydraulic fluid and deicing fluids can be ingested by engines and APUs. Lubricating oils can be directly introduced into cabin air by leakage from engine/APU bearing seals upstream of the bleed air extraction port.’* [33] *‘Airplanes with aft mounted engines or APU* *inlets may be susceptible to ingestion of hydraulic leaks from wheel wells and other fuselage mounted drains. Hydraulic fluid ingestion events have been documented during use of thrust reversers and as a result of APU inlet air ingestion of hydraulic fluid from line failure and hydraulic fluid accumulation in the aircraft belly.'* [33] The aircraft hydraulic system requires pneumatic pressure to pressurise the hydraulic reservoir via a hydraulic pressurisation module and thus avoids hydraulic pump cavitation. If this hydraulic pressurisation module fails then hydraulic fluid may enter the pneumatic system and thus find its way through the air-conditioning packs and into the cabin. Likewise deicing fluids can enter the bleed air system when drawn into the APU or engine intake during or after deicing takes place.

2.2.6 Auxiliary Power Unit (APU)

Another source of Bleed Air can come from an Auxiliary Power Unit (APU) but this is usually only used on the ground or in some cases for take off and landing. The APU is a relatively small self-contained engine, which provides air for the air conditioning *'packs'* but also as the necessary air source to start the engines or electrical power. The Boeing 727 in 1963 was the first jetliner to feature a gas turbine APU, allowing it to operate at smaller, regional airports, independent from ground facilities. APUs are now common on most commercial aircraft and can also provide electrical power in the air, as well as on the ground. APUs are usually mounted at the rear of most commercial jet aircraft.

2.2.7 Engine/Bearing Oil Seals

Seals are used to prevent oil leakage from the engine bearing chambers, to control cooling airflows and to prevent ingress of the mainstream gas into the turbine disc cavities. In the context of ensuring compressor bleed air is not contaminated with engine oil various different types of seals have been designed to try and achieve the engineering goal of only allowing air and not engine oil to leave the engine as bleed air. However, there are several inherent problems with bleeding air from an engine in relation to these seals. Due to the basic design of seals, operational practices and maintenance issues such as seal deterioration (including changing maintenance practices to detect this), it is impossible to design a mechanical seal which throughout its life will always ensure no engine oil contaminates the air supply. This inherent basic design flaw was acknowledged by the former head of the Australian Civil Aviation Safety Authority (CASA) in evidence to the 1999-2000 Australian Senate investigation into contaminated air on aircraft by stating oil fumes leaking into the aircraft air supply is *'a feature of the basic design of air–conditioning systems in aircraft being bleed air from engines.'* [153] Additionally many engine seals function less efficiently during transient engine operation such as during acceleration or de-acceleration of the engine or while the engine is achieving optimum operating temperature. [154,155] SAE recently advised: [33]

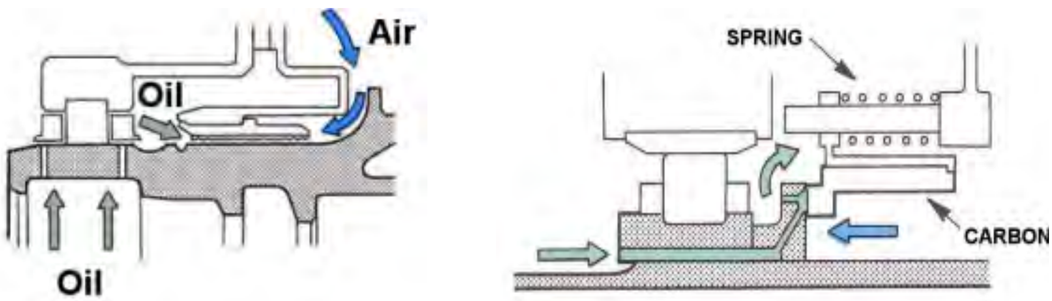
- *'It is possible in some designs that lubricating oil may leak at greater rates when an engine or APU is started and seals not yet at operational pressure and temperature or during transient operations such as acceleration/deceleration. Some systems rely on internal air pressure to maintain the sealing interface. When an engine shuts down this interface is opened, possibly allowing some oil to exit the oil wetted side of the seal. Upon engine startup, this oil is entrained into the air entering the compressor of the engine. The seal interface is again established when the engine internal air pressure returns to operating norms.'*

The FAA clearly indicated that oil leaking into the cabin air was a design problem when undertaking it's internal research before issuing an airworthiness directive (ISB 21-156/AD 2004-12-05) for the BAe 146 related to oil fumes in 2004. The FAA worksheet lists oil leaking into the bleed air as a *'design problem.'* [156]

As will be seen in chapter 6, during the 1950s there was considerable industry awareness about the critical operation of seals used with bleed air systems and oil leakage. The use of engine oil bearing seals pressurized with air that are responsive to variations in engine operating conditions was clearly recognized. [157]

A selection of different types of seals can be used in jet engines. Two seals worth examining more closely are the carbon and labyrinth seals as shown in Figure 2-8. The choice of which type of seal is used by an engine manufacturer will be dependent upon the surrounding temperature and pressure, wearability, heat generation, weight, space available, ease of manufacture and ease of installation and removal. [158]

Figure 2-8 : Labyrinth/carbon seals



Labyrinth Seal

Carbon Seal

Positive seals, such as carbon face seals used in hotter temperature areas such require a more complex seal assembly and higher requirements of surface finish or flatness and have a finite rate of wear. [159] Carbon seals consist of a static ring of carbon, which constantly rubs against a collar on a rotating shaft. Several springs are used to maintain contact between the carbon and the collar. This type of seal relies upon a high degree of contact and the heat caused by friction is dissipated by the oil system. [158]

The BAe 146/146 RJ is powered by the Honeywell ALF-502 or ALF-507. Drive shafts extending from the bearing compartments are sealed by the use of carbon faced seals as primary seals. [139] *The carbon seals are lubricated and cooled by the oil that is inside the respective bearing compartment. If an oil leak should arise from one of the engine's forward bearing compartments, this is from experience perceived at once as the smell of oil in the cabin... This engine type does not have so-called knife-edge seals* [sic labyrinth] *to back up the carbon seals at the number one bearing compartment (inlet to high-pressure axial compressor). Knife-edge seals are found in many engine types and are a non contact method of maintaining the desired pressure distribution within an engine, one function of which is to reduce oil and oil mist entering the gas flow.* [139]

Problems with the carbon face seals of the No 1 or No 9 bearings in the engines and the APU cooling fan seal have been reported on the BAe 146 engines, generally associated with failure or defects within these carbon seals allow oil to enter the main gas stream and hence contaminate the bleed-air offtake. [85] *'Failure or defects within these carbon seals allows oil to enter the main gas stream and hence contaminate the bleed- air offtake. Consideration of the design of the air offtake system on the engines of the BAe 146, where all bleed-air is taken from the output of the HP compressor, raised the possibility that this may have exacerbated the fumes problem, in that the bleed-air temperatures are the highest to be found in the compressor section of the engine.'* [85]

A labyrinth seal comprises a finned rotating member with a static bore, which is lined with a soft abradable material, or a high temperature honeycomb structure. On initial running of the engine the fins lightly rub against the lining, cutting into it to give a minimum clearance. The clearance varies throughout the flight cycle, dependent upon the thermal growth of the parts and the natural flexing of the rotating members. Across each seal fin there is a pressure drop which results in a restricted flow of sealing air from one side of the seal to the other. When this seal is used for bearing chamber sealing, it prevents oil leakage by allowing the air to flow from the outside to the inside of the chamber. [158]

The common use of labyrinth seals, was said to be reasonably effective when designed and operated appropriately but could lose performance fast when seal wear occurred or during certain thermal or transient conditions. [160]

The Rolls Royce RB211-535E4 engine used on the Boeing 757 has its engine main shaft bearings sealed by a combination of labyrinth and grooved air seals. Labyrinth seals are widely used to retain oil in bearing chambers and as a metering device to control internal airflows. The seals rely on pressurised air taken from the intermediate compressor acting on the external side of the seals to prevent oil leakage from the bearings.

The seal prevents oil leakage by allowing the air to flow from the outside to the inside of the chamber. This flow also induces a positive pressure, which assists the oil return system. The functionality of the seal design is directly related to the air pressure on the seal and as such is designed to contain oil within the bearing chambers; air enters the annular space between the oil and air seal, where the controlled leakage of air maintains the pressure at a volume greater than that in the bearing chamber. The consequent airflow through the oil seal opposes any escaping oil and carries it back to the bearing chamber, where any pressure build up is prevented by venting. If there is a leakage in the air system, or the air system supply is inadequate, the pressure could be less than that of the oil pressure, allowing oil to escape and enter the air side of the engine. Variations in air pressure may result in oil passing the seal and contaminating the bleed air supply.

The seals on the RB211-535 series engine have been the subject of a number of service difficulties resulting in the contamination of the bleed air supply. [161,162,163] For example service experience has shown that when the air pressure in the vent system rises due to technical malfunctions or over filling of the oil system, the air pressure increases in the bearing chambers. The pressure differential between the air in the bearing chambers and the external sealing air causes oil to be forced outward, past the bearing air seals. Oil leaking out of the LP shaft front bearing seals can enter the compressor drum and be centrifuged outwards and will eventually find its way into the compressor air path. The oil mist produced may be then drawn into the bleed air supply via the high pressure compressor bleed air off-takes and then fed into the cabin air conditioning system, generating hot oil smells and fumes in the cockpit and passenger cabin. [164,165]

Oil fog and oil vapor produced in the bearing regions may be transported through labyrinth seals opposite to the buffering fluid flows. Leakage can occur by diffusion of oil due to concentration gradients and by oil transport due to vortical flows within the rotating labyrinth cavities. [166] Seal deterioration also results in an unbalancing of the bearing cavity flows.

Consequently, both forms of oil seal design can be prone to failure or malfunction and therefore *'all engines leak oil from its seals and bearings'.* [123]

When a seal fails or leaks there are also no fail-safe systems present to prevent the air supply becoming contaminated with pyrolised engine oil as bleed air is not filtered. As such, unless aircraft are fitted with bleed air filtration systems, a *'bleed free'* philosophy as used on the Boeing 787 is the only solution available for aircraft designers seeking to ensure the bleed air always remains free of contaminants.

2.2.8 Recirculated Air

'Re-circulated air' is very different to *'bleed air'* and came about in an effort to reduce operating costs. While the DC9 and B737-200 use non recirculated bleed air to supply the cabin air, most modern commercial jet aircraft and engine manufacturers reduce the bleed air requirement by re-circulating some of the cabin air and therefore put less demand on the engine for bleed air. NASA, McDonnell Douglas and an airline developed *'highly efficient recirculation systems'* as studies showed that large fuel savings could be generated without compromising air quality. [137] This was accomplished by using recirculation systems equipped with *'highly efficient filters'* (HEPA filters) and correspondingly reducing the bleed air. [137] *'Air in the cabin can be recirculated to maintain comfortable ventilation rates but the quality of the air tends to decrease due to entrainment of smoke and odors.'* [136] However there is an optimum rate at which air can be recirculated, that is the minimum bleed air extraction that maintains a comfortable cabin. [136] In jet aircraft, filtered/re-circulated air combined with outside air came into use principally with the introduction of high-bypass-ratio fan engines. At Boeing, this began with the B747 in 1970. [167] This idea has evolved over thirty-five years until today when about 50% of the cabin air is re-circulated air and 50% is bleed air. In a 50% recirculated system, the outside airflow will refill the air space in the cabin every three to five minutes. [168]

Re-circulated air is not fresh air, and given the large numbers of passengers on an aircraft, there are high concentrations of particulates (fibres, dust, skin particles), bacteria (up to 30,000 bacteria per minute per passenger can be released into the cabin environment from skin scales), other micro-organisms, as well as odours. [169] Bacteria thrive in high humidity, and viruses in low humidity. Both conditions are found on commercial aircraft.

2.2.9 HEPA filters

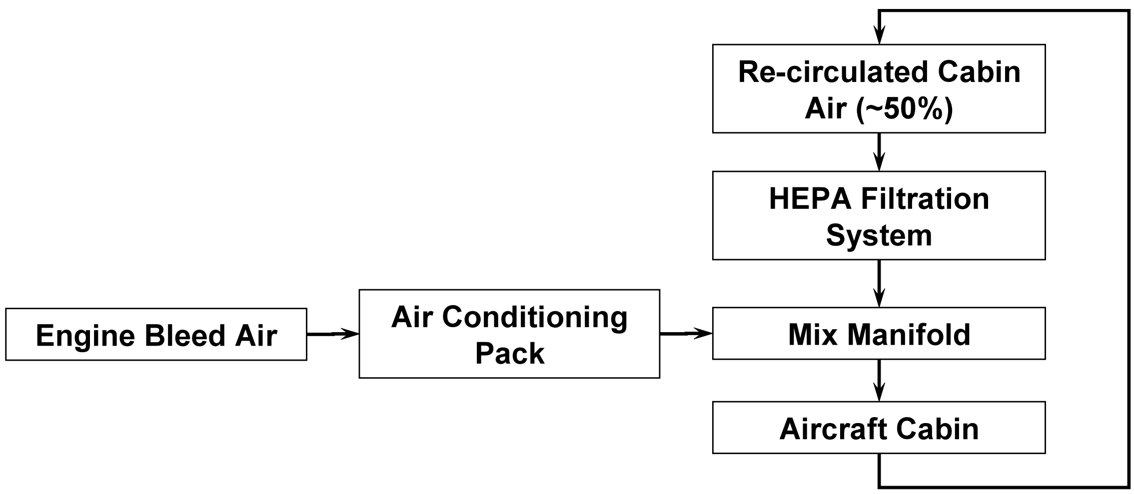
To remove particulate contamination including bacteria and viruses the re-circulated air can optionally be filtered by way of High Efficiency Particulate Air (HEPA) filters. HEPA filters are not designed to remove gases which are only removed by dilution with further incoming high quantities of outside air. [137]

Gases and vapours will pass through a HEPA filter, unrestricted, due to the small molecular sizes. *'Cabin air particulate filters (HEPA) are normally located in the recirculation loop and these are usually 99.97% - 99.99% efficient and provide excellent standards of particulate contaminant removal and control of micro-organisms from the recirculated cabin air. However, some particulate contamination, odour causing compounds and volatile and semi-volatile organic compounds (VOCs and SVOCs) may enter from the outside air system where filtration is not normally provided.'* [170]

HEPA filters used in the aerospace industry are similar to those used in hospitals. However, in the critical areas of hospitals where these are used, they filter outside air for removal of particulates and aerosols, not to re-circulate potentially infectious air.

The re-circulated air-filtration systems are placed beside the Mix Manifold so that the cabin air that is to be re-circulated passes through the air-filtration system before it enters the Mix Manifold where it is the mixed with the incoming unfiltered outside air. A simplified flow chart (see Figure 2-9) shows a typical air supply system used today on commercial jet aircraft. Only the re-circulated air is filtered by HEPA filters. The Bleed air is not filtered and it is through bleed air that contaminated air enters the aircraft.

Figure 2-9: Flow Chart of Recirculated Air



HEPA filters used for the re-circulated air provide a minimum capture efficiency (most penetrating particle size) at about 0.1 to 0.3 micron particle size, however should also be able to capture viruses down to 0.01 μm and below as well as bacteria and other particulate matter including tobacco smoke up to 10 μm.

2.2.10 Combined HEPA and Activated Carbon Filters

As the majority of cabin air recirculation filters take out particulate contamination only, combined particulate and odour removal gaseous filters (combined HEPA and active carbon filters) are utilised on selected aircraft installed in the recirculation line. These filters are able to remove particulates, odours and Volatile Organic Compounds (VOCs) in the form of gaseous contamination from the recirculated air. [168,171] However only minor gaseous contaminants from VOCs from cabin sources will be removed from this recirculated air such as bio-effluents, food and drinks. [172] As these combined filters remove gases and vapours from the recirculated air only, they will not remove contaminated air substances directly from the bleed air (bleed air must go through the cabin before it gets to the filters in the recirculation system). [171] The suggestion that the combined HEPA and gaseous activated charcoal filter will *'provide total contaminant protection'*, [171] is incorrect. Additionally, while filters containing carbon can absorb VOCs and some gases, they will be effective only until the carbon is saturated. After this they will not work and *'breakthrough'* leakage will occur. The activated carbon will capture gases up to the saturation level of the carbon with efficiency depending on the activated carbon type. [173] Some aircraft such as the BAe 146 can utilise carbon activated cabin and flight deck filters which filter limited contaminants dependent on chemical composition from the bleed air and recirculated air. However, these filters are only suitable for low temperature applications and subject to carbon saturation.

2.2.11 Outside bleed air

Gaseous contaminants from the bleed air are controlled by dilution assuming the source of the air is cleaner than the air that is present or where ozone converters are used by chemical (ozone) conversion. [174] Some aircraft are fitted with combined ozone and odour reduction converters, which in addition to removing ozone also remove gaseous odours entering the cabin via the bleed air system during ground operations, that is push back and taxiing. [172,175]

It is acknowledged that particulate, odour compounds and *'trace'* chemical VOCs may enter from the outside air system via the mixing chamber where filtration is not normally provided. [176] The main contaminants to be removed are particulate, odours/VOCs and *'sometimes'* oil mist. [177] Some manufacturers have applied a *'low temperature application'* carbon adsorbent filter for VOC/odour removal of the outside air, usually consisting of disposable filter elements. [176] Such carbon adsorption filters can work effectively up to 70°C, however the filter efficiency decreases as contaminants accumulate on the adsorbent, so the elements require removal and replacement at regular maintenance intervals. [176] At present these filters are an option on the Airbus A320 and A330/340 family, BAe 146 and are standard on the BAe 146 RJ. In the past they have occasionally been installed on the MD11, B737 and B757 aircraft. [176]

Boeing and Pall Aerospace (a filter manufacturer) found that chemical absorption/adsorption filter methods such as the use of charcoal technology used to remove gaseous contaminants from the outside air supply are not suitable due to technical issues, temperature limitations and the devices could become sources of contaminants. [168,174] *'Based on the aerospace industry experience with ozone converters, it is known that catalytic converters accumulate contaminants and gradually lose efficiency as they accumulate operating hours and cycles. In addition, these units may be poisoned by "episodic" fume events, when a high concentration of oil contamination enters the air system in a short time interval.'* [170]

New technologies in the hot sections of the ECS are under consideration. [168,178] These include regenerable VOC systems including: photocatalytic oxidation (PCO) for VOC/odour removal; and non thermal plasma oxidation for removal of particulate and VOC/odour compounds. [176,177] Outside air filtration could be achieved by low temperature carbon adsorption; high temperature media for particulate removal or high temperature catalysts for VOC/Odour removal. [177] However, as seen the carbon adsorption disposable filter elements are only suitable for low temperature applications, require removal and replacement at frequent maintenance intervals. [177] In addition to removing VOC and odour components from the outside air, filtration media for particulate removal needs to be considered. Filtration of the pneumatic bleed air is necessary to protect the ECS from damage caused by particulate contamination, such as fine carbon, dust, sand and oil mist or droplets. [176] If not removed, these contaminants can adversely affect the performance of the ECS and its components. The selection of the filter media will depend on the location of the filter (high or low temperature) as well as they type of contaminants that need to be removed.

Non-thermal plasma oxidation is suitable for the treatment of gas streams with low VOC concentrations and can be used for the simultaneous destruction of different airborne pollutants, such as dust and microbes. The residence time of the contaminated gas in the plasma reactor has to be long enough to allow complete oxidation of the VOCs/odour compounds. If the residence time is too short, partially oxidised reaction intermediates will be returned to the aircraft cabin in the recirculated air stream and it is possible that these new compounds will be equally as unwanted as the original compounds or could possibly be more toxic. It is also vital to ensure that the nature of the cabin air contaminant is known before the treatment is applied in order to avoid the production of unwanted oxidation products. [170] This form of filtration has been marketed by BAe and has been identified as problematic. [179,180]

A newly developed Pall Photocatalytic Regenerable Adsorption (PCRA) system uses a combination of adsorption and photocatalytic oxidation to remove particulate and gaseous contamination from the cabin air supply. [170] The adsorbent adsorbs the gaseous contaminants and then the system oxidises the contaminants on the adsorbent and they are purged overboard into atmosphere. *'The advantages of the PCRA is that it is a fully regenerable adsorbent system therefore maintaining high efficiency throughout its period of operation, it removes the contaminants from the air stream rather than oxidize them, it can operate at ambient cabin temperatures, it does not generate ozone.'* [170]

All these new technologies have pros and cons and need to be carefully considered. In order to provide a safe, healthy and comfortable environment for passengers and crew, consideration for '*adequate*' purification of the outside air is required for both existing and future aircraft. [176]

2.2.12 ‘Bleed Free’ designs

The new Boeing 787 has been designed with a new system for supplying air to the passenger cabin and flight deck, which is not based on bleed air. In the Boeing 787 conventional bleed air is replaced by electrically driven pneumatic systems, which will be more efficient than bleed air and making the aircraft more fuel efficient. The Bleed Free philosophy used on the Boeing 787 ‘*will have a no-bleed architecture for the outside air supply to the cabin. This architecture eliminates the risk of engine oil decomposition products from being introduced in the cabin supply air.’* [181]

2.2.13 To Summarise

Bleed air was developed as a means of providing pressurised air to the cabin. Because of their design, by virtue of their design current engine oil seals can and will leak oil into the air supply system. Current and future filtration technology can never be designed to be 100% effective and reliable throughout its service life. Consequently, the only effective long term solution to address the problem of bleed air contamination by hydraulic fluids, engine oils and their by-products is the introduction of bleed free architecture in all future aircraft designs as is used on the Boeing 787.

2.3 What's in the Oils?

2.3.1 Introduction

Synthetic jet engine oils, hydraulic fluids and deicing fluids contain known neurotoxins and skin sensitisers and a range of other hydrocarbons. These substances represent an appreciable hazard due to selected toxic ingredients, but are safe in normal use, provided maintenance personnel follow appropriate procedures and the substances do not escape from the enclosed operating systems they are intended for. That is oils should stay in the engine and when leakages occur, human exposure will take place through uncontrolled exposure. [182] Oil leaking into the aircraft cabin air supply is not considered normal use of the product. [183,184]

Jet engine oils will be subject to extreme heat whilst hydraulic fluids will be used under very high pressure. Should these leak into the air supply, by virtue of the fact these are enclosed environments, occupants will be exposed as they are unable to remove themselves from the environment where these exposures take place. Additionally, it is the mixture of substances that is of interest in addition to the exposure from the individual chemical ingredients. Oil or hydraulic fluid leaks from an engine may be in the form of unchanged, degraded, combusted or pyrolised oil/fluid in the form of gases, vapours, mists and particulate matter. [182,185]

A review of the various substances found in the cold unheated products is a necessary initial step to understand the hazards of exposure in an aircraft environment.

2.3.2 Synthetic jet engine oils

Decades after *'breakthrough lubricants'* were developed for the first automobiles, unique lubricant molecules termed *'synthetics'* were discovered and seen as a second revolution in lubrication technology - one that would drive equipment efficiency, reliability, and productivity far beyond what was possible with ordinary oils. [186] Synthetic oils were developed initially to act as conventional oils due to the threat of shortages of crude oil supplies due to rapid growth after World War 2 (WW2). Their aims, like for conventional oils, were to lubricate metal parts, incorporate chemical additives needed to protect metal parts from contaminants and by products formed during use, and to keep rubber seals pliable and leak free. [186] However, with the rapid advance of aircraft engine development, synthetic engine oils became even more necessary due to the higher performances required, leading to the development of performance enhancing additives. Conventional oils made from crude oil contain a variety of molecules with varying performance with tendencies to break down easily causing sludge and become too thin or thick at higher or lower temperatures respectively. However, synthetic oils are *'designer fluids'* whereby the molecules stay together at higher temperatures, keep the metal surfaces clean and maintain the required lubricant film. The oils are virtually wax free and therefore flow at low temperatures and can meet a variety of viscosity requirements. [186] As such, gas turbine engines use low viscosity synthetic lubricating oils, which do not originate from crude oil or mineral oil. [187]

Synthetic jet engine oils are made up of a base stock, antiwear additives, corrosion inhibitors, and antioxidants. [188] These oils used in high performance jet engines are manufactured to meet strict standards (varying grades), such as US Navy MIL-PRF-23699, UK MOD Def. Stand 91-101, NATO O-156 or MIL-PRF-7808K, NATO O-148. The determination of the various compounds is not mandatory in the various standards. [188,189,190] In recent years some manufacturers have required additional test requirements over MIL-PRF-23699 as a response to performance concerns such as coking, O-ring deterioration, load carrying ability etc. and the need for HTS (higher thermal stability) grade along with quality, traceability issues and the need to free up DoD activities. [191] Therefore, a recently developed SAE technical standard for qualification of oils to be used in civilian operations, AS5780, is now the mandatory technical reference endoresed by regulatory authorities. [191,192] Further new high performance capability lubricants have been developed. [191]

There are many considerations to take into account when choosing suitable oil including: reduction of friction/antiwear properties, cleaning, cooling and sealing/seal compatibility, anti foaming, oxidation inhibitors and corrosion inhibition. [193]

Three centistokes (cSt) viscosity oils (such as BP2389 or Turbonycoil 160) are qualified to MIL-PRF-7808 and are used almost exclusively in military engines and APUs and occasionally in commercial aircraft APUs because using oil with a lower viscosity (3 cSt) enables easier reignition of the APU inflight. Five cSt (more viscous) oils qualified to MIL-PRF-23699 or AS5780 would include MJOII, MJO254, BP2380, BP2197, BP2189, Aeroshell 560 and TurboNycoil 600.

Tertiary organophosphate esters have been known about for over 150 years, with the development after WW 1 of less flammable lacquers using an OP ester (TCP) as industrial and automotive coatings, leading to the investigation of phosphate esters as safer hydraulic fluids and lubricants. [194]

While phosphate esters have been used as antiwear additives in industrial applications since the 1930s the application to use ester based lubricants for military and subsequently commercial aircraft was developed after World War 2. [195,196] The US Navy had found that esters could be used for special purpose lubricants in military applications in aircraft with further research undertaken by a German research group. [197,198] Given the problems with mineral oils and advancing use of gas turbines, the military is known to have commenced using synthetic oils in quantities since at least 1951. [199]

All jet engine oils use phosphate antiwear additives so as to avoid rapid wear of engine components, which would lead to failure. [196] The antiwear additives are based on phosphorus compounds comprising not more than 3% of the formulation, while the antioxidants used are made up of hindered phenols, aromatic amines in a range of concentration of 0.25-5%. [188] The antiwear phosphate esters have become commercially useful products, despite recognition of their neurotoxicity and are now commonly used in vapour phase lubricants with triaryl phosphates being the most widely used. [200]

The base stock used in the synthetic oils will vary with the main composition prepared from neopentyl (polyol) esters, which are obtained from the esterification of pentaerythritol (PE), dipentaerythritol, and or trimethylolpropane (TMP/TMPE) with C_5-C_{12} monocarboxylic (fatty) acids. [201] The polyol ester component of the base stock made up of pentaerythritol and or trimethylolpropane may be varied to change the viscosity of the lubricant. [202]

The varying carboxylic acids are linked with the odours associated with cabin oil events.

Synthetic jet engine oils have been used in aviation for many years and remain essentially unchanged. Mobil Jet Oil II (MJO II), a second generation jet oil, (developed under newly created MIL spec MIL-PRF-23699, 1963) [203] which commands almost half the synthetic jet oils market share, [184] has remained almost unchanged since its development in 1963. Most changes to MJO II have involved *'slight revisions of the ester base stock due to changes in raw material availability.'* [204]

Synthetic oils and not mineral oils are used in turbine engines as they retain their lubricating properties and are more resistant to oxidation at high temperatures and have better thermal stability and viscosity characteristics. While second generation synthetic oils are still widely used third and fourth generation oils have since been developed. Some of the features, advantages and potential benefits listed by the manufacturers are shown in Table 2-1. [205]

Table 2-1: Changes in Oil Performances from 2^{nd} to 4^{th} Generation Oils

Name of Oil	Generation	Properties
Mobil Jet Oil 2	2^{nd} Generation	Excellent thermal and oxidation stability Reduces formation of carbon and sludge Maintains engine efficiency and extends engine life Reduces engine maintenance Lengthens gear/bearing life Effective lubrication at high operating temperatures Lowers oil consumption
Mobil Jet 254	3^{rd} Generation	Reduces bulk oil oxidation by 50% Reduces sludge, carbon deposit formation Reduces engine maintenance Extends seal/bearing life Lowers oil consumption Deposit control increased by 50ºF

Name of Oil	Generation	Properties
		Excellent resistance to foaming
Mobil Jet 291	4th Generation	Very low vapour/mist deposition Toxicologically safe additive High temp, jet oil cleanliness, reduced formation of carbon and sludge deposits Enhanced load carrying ability Excellent bulk oil stability Excellent elastomer compatibility (Maintains good seal performance and minimises leakage) Excellent resistance to foaming

However, selected oils are noted to have operational problems such as seal swelling with silicone elastomers noted to be problematic for MJO 291 necessitating reformulation due to the load carrying booster attacking silicone based elastomers. [206] MJO 291 was removed from at least some approved lubricant lists (Honeywell) [206] and has since been discontinued, as it was incompatible with *'certain components in the engine oil system and oil system coking'* occurred. [207,208] A new generation synthetic oil, BP Turbo Oil 2197 advises the benefits of the oil include excellent *'thermal and oxidation stability, outstanding high temperature cleanliness and superior hydrolytic stability.'* Additionally the product data sheet states *'Users of this oil have been enjoying cleaner engines, i.e., less or no carbon deposits in oil supply and scavenge tubes or bearing compartments and some of them also experience less frequent oil filter replacement*.' [209] However BP 2197 was noted to be incompatible with the O-rings on the PW 4000 engine as the new oil was deteriorating the O-rings. [210]

One critical factor concerning compatibility of synthetic turbo oils is the effect different oils may have on elastomers, such as "O" ring seals even if both oils are approved under the same specification. There have been, and probably will continue to be, incidents of incompatibility. Certain synthetic turbo oils tend to swell seals while others may tend to shrink seals. Use of one oil brand with acceptable seal swell limits followed by an oil brand with acceptable shrink limits could cause oil leakage particularly in high time gas turbines where a seal(s) had taken a permanent set. [211]

The deposit forming tendancies of the lubricant depend on the oxidative stability of the ester (base stock), polarity of the ester, process residuals and additives. [212]

Given the concern about weight and associated cost penalties in aerospace applications, minimum volumes of fluids and lubricants are used resulting in extreme levels of stress in very high and low operating temperature environments. However, in an attempt to improve fuel efficiency of turbine engines and to meet more severe operating environments, higher operating temperatures were predicted. Therefore, improved ester based lubricants would be required using a careful balance of ester base stocks and improved additives. [213] As such, revisions of the oil specifications have taken place over the years. However, according to Royal Dutch Shell, *'some commercially available lubricants are being stressed to the limits of the fluids capabilities'* [203] and further advanced engine concepts will require utilisation of different classes of synthetic lubricants. [213]

The hazardous ingredients in a typical synthetic (MIL-PRF-23699) jet engine oil, Mobil Jet Oil II (MJO II) can be found by reviewing their Material Safety Data Sheets (MSDS), product data sheets, oil packaging material and other oil company data. Information supplied has varied considerably over the years, despite product formulations having remained virtually unchanged.

Mobil Jet Oil II is listed as being made up of: [182,214]

- synthetic esters based in a mixture of 95% C5-C10 fatty acid esters of pentaerythritol and dipentaerythritol;
- 3% of the organophosphate tricresyl phosphate (TCP) (Phosphoric acid, tris(methylphenyl) ester, CAS Number 1330-78-5);
- 1% N-Phenyl-alpha-naphthylamine (PAN) (phenyl-alpha-naphthylamine; 1-Naphthalenamine, N-phenyl, CAS Number 90-30-2), PAN contaminants;

- Variously reported mixture of 0.1%-1% octylated diphenylamines: Benzamine, 4-Octyl-N-(4-Octylphenyl), Dioctyldiphenylamine (DODPA) (CAS Number 101-67-7); N-Phenyl Benzeneamine, reaction product with 2,4,-Trimethylpentene/diphenyl amines alkylees (CAS 68411-46-1).

Additionally β-Napthalenamine (BNA) (2-Napthylamine, CAS 91-59-8) at up to 50 ppm (0.005%) and Phenyl-beta Napthylamine (PBN) (N-phenyl-2-naphthylamine CAS 135-88-6) at up to 5000 ppm (0.5%) listed on previous MSDSs are said to be trace impurities of PAN, which is in the oil at approximately 1%. As such BNA could potentially be in the oil at 0.00005% (0.5 ppm) while PBN could be in the oil at up to 0.005% (50 ppm). [215] Other named impurities of PAN include 1-Naphthylamine (ANA, CAS 134-32-7). While these were listed on the 1992 MJO II MSDS they have since been removed as they were considered to be in the PAN only at trace levels and in the MJO2 at negligible to non-existent levels in MJO2 with their inclusion only raising unnecessary public concern regarding the *'presence of potential carcinogens in the product.'* [183,215]

Various Mobil documentation also list *'contents partially unknown'*, *'proprietary and not available'*, *'proprietary metal passivator ~0.2%'* and *'silicone deformant ~0.01%.'* [216] The MJO II MSDS generally state TCP is in the product at 1-5% (generally around 3%) using CAS 1330-78-5. However as oil companies do not provide all details on the oils, estimating the exact toxicity is not possible. [139]

An alternative oil, BP Turbo Oil 2380 is also a 100% synthetic jet oil with the MSDS variably listing TCP (CAS 1330-78-5) at <3% (<0.1% ortho isomer) and mixed aromatic amines at <5%. [217] Similar, later BP turbo oil MSDSs list TCP at 1-5% (no longer listing the ortho isomer content) and PAN (CAS 90-30-2) at 1-5%. However the TCP and PAN quantities are thought to actually be around the same quantities as MJO II. The AeroShell 500 MSDS is similar to the Exxon Mobil and BP Turbine oil MSDSs listing proprietary additives at <1%, TCP at less than 2% and amine anti-oxidant at <3%. [216]

Other ingredients listed on some MSDS synthetic jet engine oils include *'aniline'* reported present in BP 2380 and BP 2389 [218][219] and *'phenothiazine'* reported present in BP 25. [220]

The types of oil base stocks used in an engine oil formulation are never reported on the MSDS sheets apart from a generic statement such as *'Synthetic base stock (90-100%)'* in some cases only. Patent data on base stocks indicates such products are proprietary information.

NYCO, a French company entered the synthetic lubricant market in 1959 and developed TURBONYCOIL 13B for the French Mirage fighter. TURBONYCOIL ® 600 formulated under the specification MIL-PRF-23699 was approved in 1985 and is used today by the U.S. Navy and extensively by military agencies worldwide. It is also approved for many commercial engines and APUs. It is quite unique as it does not contain TCP at any measurable quantity. [221] The triaryl phosphate, Tri-isopropyl phenyl phosphate (TIPP) CAS 68937-41-7 used in TurboNycoil 600 at 2.3%, was selected as the antiwear additive to be used after the French Health authorities advised NYCO of its toxicity concerns with TCP as listed in table N°34 of the occupational diseases published by French Ministry of Health. TURBONYCOIL 600 is seen as a straight equivalent to MJO II and BP Turbo Oil 2380. The TurboNycoil 600 MSDS based on NYCO's testing of it's additive (TIPP; TPP) and the additive TCP/TOCP, has recently been updated to include the presence of TIPP and lists the following risk phrases Xn R62.F3 and R 63.G3 - possible risk of impaired fertility and harm to the unborn. Triphenyl Phosphate (CAS 115-86-6) is also listed at <2.5%. [222] The MSDS also contains a statement that 'vapours or mist of heated product may be harmful by inhalation.' [223] However, other oil producers have not amended their MSDSs to reflect these findings. NYCO has advised that it has therefore developed a new oil formulation (under patent) that potentially has reduced toxicity by several orders of magnitude over the same content of TCP (MIL-PRF-23699 Class HTS) with no PAN. [222]

2.3.3 Base stocks

While the commercial base stocks used in jet engine oils are not commonly known, it is understood that most are based on polyol esters of pentaerythritol (PE – CAS 115-77-5) making up around 95% of the oils. Polyols or *'hindered esters'* are made by reacting a multifunctional alcohol with monofunctional acids for which variations in the raw materials can have a major influence on the final physical properties of the ester. [212] Saturated short chain fatty acids (C8-C10) are used to make high stability polyol esters used in high performance jet engine lubricants. [212] Various additives can be used to improve the oxidative stability of ester lubricants, such as antioxidants, antiwear additives, metal passivators and metal deactivators, however such mixtures have been found to be synergistic and additives can markedly reduce the stability of an ester. [212]

BP 2380 and previously Exxon 85 (now discontinued) are believed to be made up of approximately 60% trimethylolpropane ester (TMP/TMPE – CAS 77-99-6) and 35% dipentaerythritol ester (CAS No: 126-58-9). BP2380 is the only 5 cSt oil using TMP as a base stock and supplies 40% of the free world airline demand for 5 cSt synthetic turbo oils according to BP. [211] The Exxon Turbo Oil 85 (now withdrawn) base stock was previously made up of 100% TMP esters. Oils belonging to MIL-PRF-7808 standard, used mainly in the military, also use TMP ester base stocks (e.g. BP 2389) at around 75-85% TMP esters. As there is little or no information available on the esterified TMP or PE chemicals as distinct from the original product (TMP is listed as causing mechanical irritation to the eyes and respiratory tract), it is not possible to draw any conclusions from the base stocks used in the oils based on their own. However, there are considerable data available clearly identifying concerns about the reaction of TMP with TCP.

TCP and trimethylolpropane esters (TMP/TMPE) can react together and form trimethylolpropane phosphate (TMPP), a potent neurotoxin. However this has not been reported to have been found in aircraft to date. However, US Navy studies have found that under laboratory conditions, Exxon 2380 engine oil demonstrated that *'large quantities'* of TMPP was formed very rapidly at elevated temperatures commencing at 350 deg C. [224] One other oil of MIL-L-23699C specification was shown to also demonstrate evidence of TMPP at a lower level to Exxon 2380. The formation potential of the deadly neurotoxin TMPP from the reaction of the TMPE basestock and TCP has since been found to occur at 250ºC. [225] The minimisation or replacement of TMPE base stocks with other suitable polyol esters or ways to inhibit TMPP formation reaction were recommended. [225] Additionally a recommendation was made to exclude the use of Exxon (BP) 2380 from the U.S. Navy inventory because of its high potential for TMPP production on pyrolysis and that all polyol ester based synthetic oils in the U.S. Navy inventory should be tested for the production of TMPP. [224] Importantly it was recommended that *'research should be initiated for overall toxicity of combined, combustion byproducts rather than for any individual combustion product present.'* [224]

2.3.4 Tricresyl phosphate (CAS 1330-78-5)

Jet turbine oils contain tricresyl phosphate (TCP) as well as other triaryl phosphates (TAP). [226] TCP (CAS 1330-78-5) also known as phosphoric acid, tris (methylphenyl) ester or Tritolyl phosphate is a load carrying antiwear additive in the oil most commonly at 3%. Up to 95% of jet engines have used this phosphate additive. [195] Mobil advises the antiwear properties of TCP used to increase load carrying capacity and tolerance in the high performance jet engines are unique with no other replacement identified that will meet the stringent performance requirements. [183] The critical performance requirements that are met with the use of TCP and the up to 7 year approval process to change the oils has meant that manufacturers and lubricant formulators have remained cautious about replacing the TCP additives for toxicological or indeed, any reasons. [226]

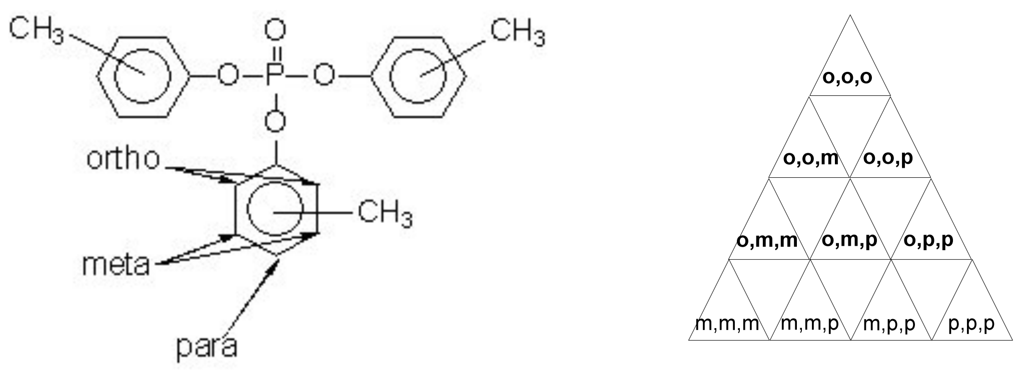
TCP is practically colourless and odourless and is a blend of ten tricresyl phosphate isomer (identical molecular formulas) molecules, plus other structurally similar compounds, including phenolic and xylenolic compounds. [226,227] Some of the TCP compounds are potent neurotoxicants. [226]

The term TCP has *'has generally been used rather loosely to describe triaryl phosphate preparations which may contain… a mixture of triphenyl phosphate, tricresyl phosphates, trixylenyl phosphates and trialkylphenyl phosphates. Each of these components has several sterioisomers which may differ in their toxicity, so that a total number of compounds in a given preparation may be very large.'* [228]

The original source of raw materials for triaryl phosphates was coal tar which was distilled to produce mixtures of cresols and xylenols. [229] These were subsequently reacted with phosphorus oxychloride to produce phosphate esters known as *'natural phosphates'* with the resulting phosphates being a complex mixture due to the large range of cresol or xylenol isomers present. TCP is therefore a mixture of various triaryl phosphates. [230] With the introduction of natural gas, the availability of coal tar declined and industry commenced manufacturing *'synthetic'* triaryl phosphates made from alkylated phenols produced by reacting phenol (from petroleum) with isopropylene or isobutylene. [229] Synthetic feedstocks are widely used for the production of natural phosphates. [229] The term natural phosphate esters is used to describe tricresyl/trixylyl phosphates (TCP/TXP) (using synthetic feedstocks) as distinct from isopropylated and tertiary butylated phenyl phosphates (IPPP/TBPP). [229] As one of the major disadvantages of early TCP/TXP production was neurotoxicity with investigations revealing that ortho cresol in the feedstock feedstock was converted to TOCP with the o-cresol (raw material of the *'synthetic fluid'*) content now strictly controlled to very low levels. [229]

TCP is a molecule comprising three cresyl (methylphenyl) groups linked to a phosphate group. The location of the methyl group in the cresyl group is critical for the expression of neurotoxicity, with ortho-, meta- or para- prefixes that denote how far apart the hydroxyl and methyl groups are on the cresol molecule. There are in fact 27 different combinations of the meta, para and ortho groups in TCP, however, numerous combinations are considered the same molecule such as ppm, pmp, mpp as they are optical isomers of each other. Therefore, there are in reality ten isomers of TCP that are conventionally described as shown in Figure 2-10. [182]

Figure 2-10: Isomers of tricresyl phosphate



TCP molecule showing o- (ortho), m- (meta), and p- (para) cresyl groups.

Possible isomers of TCP. *

* ortho-cresyl group containing molecules are highlighted in **bold**

Until the late 1950's the toxicity of TCP preparations had generally been related to the TOCP content, however it became apparent around that time that other ortho isomers were of equal or greater activity. [228] As the neurotoxic properties of TCP have been related to the ortho cresyl group, specifically tri-ortho cresyl phosphate (TOCP), the focus for the oil and aviation industry has always been on the low TOCP content of the TCP.

While the CAS number 1330-78-5 refers to TCP as a whole or a mixture of isomers, two other CAS numbers are sometimes used to further differentiate between the ortho-cresyl isomers of TCP and the meta and para or non ortho-cresyl phosphates of TCP:

CAS No 78-30-8: Tricresyl phosphate (containing o-o-o; o-o-m; o-o-p; o-m-m; o-m-p; o-p-p ortho-cresyl groups)

CAS No 78-32-0: Tricresyl phosphate containing meta or para isomers only (containing non ortho-cresyl groups) m-m-m; m-m-p; m-p-p; p-p-p.

Importantly, the number of triaryl phosphate combinations in TCP is very high and is not limited to the 10 that can be formed from the ortho, meta and para cresol. [183] Mobil advised conventional TCP contained ortho cresols at around 0.16%, meta and para cresols combined at 80% and other phenols at 17%. [183,226] At the same time, Mobil identified for the first time publicly that MJO II using conventional TCP contained not only TOCP at 5 ppb but DOCP at ~6 ppm and MOCP at ~3070 ppm. [183] The 0.3076% total ortho cresol isomer level in the TCP was calculated by statistical calculations from the compounds present in hydrolysates as it was not practical to measure all of the triaryl phosphate compounds as standards do not exist for most of them, yet the other various phenols and xylenols have *'virtually the same reactivity'*. [183] No other oil manufacturer had listed any other ortho cresol isomers other than TOCP.

One of the 2 global aviation TCP manufacturers in 2005 advised that in the early 1980s ortho cresol in the feedstocks was approximately 0.6% (0.9% in the late 1970s) of the TCP, while a 1993 Specification required that there be less than 0.2% ortho cresol isomers, which in practice was around 0.14% from 1993 onwards. [231] It was also confirmed that the majority of the ortho cresol isomers related to the mono ortho cresol [231] with the meta isomers at approximately 21%, para at 7% with mixed meta/para isomers at approximately 71% of the TCP and the ortho isomers at approximately 0.15% of the TCP. [232]

The manufacturer claims that *'Low toxicity TCP'* was developed for MJO291 in an effort to reduce the ortho content of TCP. It contains TOCP at <1 ppb, DOCP at ~1.1 ppm and MOCP at ~1760 ppm, or 1761 ppm ortho content with - 99% meta and para cresol and ~0.06% ortho cresol. [183]

Since 1988 when Mobil reported potential neurotoxicity of a *'contemporary'* TCP used in jet engine oil, further reductions of the levels of ortho substituents in the TCP have taken place. [226] Commercial production of TCP from 1985-1992+ *'showed lower levels of ortho-cresol content but with minimal impact on toxicity.'* [226] The conventional TCPs used in jet engine oils during the 1980s and 1990s, assuming a low ortho cresol content and resulting low TOCP level and very low neurotoxic potential were still in use in at least 1999. [183,226] Conventional TCPs including MJOII are still in use today. The *'Low toxicity TCP'* reportedly developed and used in MJO 291, has according to Exxon Mobil been discontinued. [207] While Mobil has acknowledged that there has been an attempt to reduce the ortho content of the TCP for toxicological reasons and recognized that TCP, based on it's toxicity, will not be replaced for performance reasons, they also advised that TOCP is in the oil as an impurity at very low levels and contributes *'no performance characteristics to the Jet Oil.'* [183]

As the ortho isomers of TCP are 0.376% in the TCP and the TCP is in the oil at 3%, the ortho isomers in the oil are less than 0.1% based on the TCP equivalent toxicity. The non ortho isomers in the oil come to 2.9% of the oil. Under the EU Directive 67/548/EEC, (utilised under the European and Australian chemical substances databases and approved criteria [94,104]), TCP falls below the 0.2% ortho content where a Hazardous *'harmful'* classification would be required. However the EU and Australian guidelines when taking into account synergistic effects, borderline ortho content, updated toxicity concerns of the non ortho content, and the fact that the 0.2% listed criteria level is regarded as a practical level of protection and should not be used to suggest an effect cannot occur below that level, indicates caution is required with a review warranted. If a hazardous/harmful classification had been applied, the following risk phrases would be applicable: R68/20/21/22: *'Possible risks of irreversible effects'* (non lethal after single exposure), '*Harmful by inhalation', 'harmful in contact with skin'* and *'Harmful if swallowed'* respectively. [233] Long-term or repeated exposure may have effects on the nervous system also requiring a R48 under the hazardous classification. [234] However in both the EU and Australian case, the MSDSs do not list the ortho cresol content of TCP and instead, rely on and use as of late 2009 the total TCP mixture classification CAS 1330-78-5 which is no longer listed in the EU or Australian guidelines.

Although many lubricants contain TCP as well as other triaryl phosphates at considerably below 1% according to Mobil and below 2% according to a TCP manufacturer, jet turbine engine oils most commonly contain TCP concentrations of approximately 3%. [226,235] According to a major TCP manufacturer, for the last 50 years over 90% of the phosphate ester antiwear additives used in lubricant manufacture globally have been iso propyl phenyl phosphates (IPPP) or tertiary butyl phenyl phosphates (TBPP), given the reduced toxicity concerns over TCP/TXP. [235] '*Two markets had tricresyl phosphate containing lubricants specified and did not wish to change - military and aviation. Tricresyl phosphate is still used by these markets today but the global volume is small'* and the ortho cresol content has been greatly reduced. [235]

While TCP as an antiwear additive should remain at or below 3%, [188] there is some confusion about the differing levels of the ortho cresol content requirement based on the toxicity concerns in recent years. While many suggest the ortho cresol content is required to be restricted to 1%, [189,236,237] others report the levels of o- cresol in the feedstock is or must be restricted to below 0.3% (Mobil), [238] 0.2% (TCP manufacturer, AS5780), [192,194] below 0.1% [239] and between 0.05 to 0.13% by another TCP manufactuer. [240] A 1993 Mobil published paper notes that while TOCP was reduced to below 0.5% in the TCP, little thought was given to the other isomers. [241]

The use of phosphate esters by the lubricants industry has steadily increased since the awareness in the 1940's of their excellent antiwear and fire resistance properties, particularly for hydraulic fluids and lubricants, with the basic compiosition remaining unchanged for several decades. [194]

While TCP has been a commercially useful material and has been used as a plasticiser, lubricant, hydraulic fluid, paint additive, oil additive and dust suppressant, [242,243] many commercial uses (triaryl/trialkyl phosphate esters) have now ceased with use now limited to a plasticiser in vinyl plastics, flame-retardant, additive for extreme pressure lubricants, and as a non-flammable fluid in hydraulic systems. [230] TCP (tricresyl phosphate) is now used mainly as an antiwear additive in aviation gas turbine lubricants but also by the plastics industry in Japan. [194]

There is ongoing misinterpretation of the term TCP instead of the correct terminology triaryl phosphates, trialkyl amongst others. For example the recent ASHRAE standard suggests: *'Information on the content of individual isomers of TCPs in hydraulic fluids used in the airline industry shall be made available to crewmembers.'* [24] Careful understanding of the terminology and applicable uses is required and can be found in various studies. [194,229,228,244]

2.3.5 Amine antioxidants

N-Phenyl-alpha-naphthylamine (PAN) CAS 90-30-2 is used as an antioxidant at around 1% in lubrication oils, acting as a radical scavenger in the auto oxidation of lubricants. The commercial product has a typical purity of around 99% with a number of named impurities including B-napthalenamine (BNA), Phenyl-Beta napthylamine (PBN) and 1 Naphthylamine (ANA). The concentration of 1% PAN in jet oils meets the cut off criteria of 1% for classification as an *'irritant'* hazardous substance in Australia for sensitisation properties. [94,182,185] Additionally, a risk phrase of R43 should be applied – *'May cause sensitisation by skin contact'*. BNA as a CAT 1 carcinogen and PBN as a CAT 3 carcinogen as contaminants in PAN fall below the 0.1% and 1% levels respectively in the approved criteria for classifying a hazardous substance, however BNA is listed as a prohibited substance under the Australian Hazardous Substances regulations [245] and all contact is advised to be avoided. [234]

The substituted diphenylamines (CAS 68411-46-1; 101-67-7) used as antioxidants at not greater than 1% are not listed on the Australian or EU hazardous substances databases but along with PAN have been identified in analysis of jet engine oil additives and are now listed on various MSDSs. [246]

2.3.6 Hydraulic fluids

The use of both trialkyl and triaryl phosphates as synthetic basestocks was developed by a joint program between the US Navy, Air Force and the Shell Devlopment Company between 1949 and 1953 following on from earlier 1940s research. [194] Today synthetic hydraulic fluids are widely used in the aerospace industry replacing non synthetic fluids (MIL-PRF-5606) due to their increased fire safety. Phosphate ester hydraulic fluids are described in AS 1241. The military conversion from MIL-PRF-5606 to fire resistant synthetic hydraulic fluids resulted in the developed of a new class of fluids based on polyalphaolefins (PAOs) under MIL-PRF-83282. [213]

Hydraulic fluids in commercial aviation are used in various high pressure systems. Skydrol® and Hyjet IV-A Plus® are representative of typical hydraulic fluids.

MSDS labels listing ingredients are shown in Table 2-2 and Table 2-3.

Table 2-2: Skydrol LD4

Chemical	CAS	%
Tributyl phosphate	126-73-8	58.2
Dibutyl phenyl phosphate	2528-36-1	20-30
Butyl diphenyl phosphate	2752-95-6	5-10
2,6-di-tert-Butyl-p-cresol	128-37-0	1-5
Epoxy modified alkyl ester*: 2-ethylhexyl 7-oxabicyclo[4.1.0] heptane-3- carboxylate	62256-00-2	<10%
*Trade secret/withheld		

Table 2-3: Hyjet IV-A Plus

Chemical	CAS	%
Tributyl phosphate	126-73-8	70-80%
Aliphatic Epoxide	62256-00-2	5-10%
Component(s) of product ingredients include: Triphenyl Phosphate	115-86-6	< 2.5%

The main ingredient in hydraulic fluids is usually the practically colourless and odourless tributyl phosphate, a trialkyl phosphate ester (TBP) with CAS number 126-73-8 which is used as the base stock in the formulation of hydraulic fluids. Based on the Australian Hazardous Substances Information System, TBP in a product at above 25% is listed as a *'Harmful'* hazardous substance carrying a cat 3 carcinogen classification and the following risk phrases: R40/Limited evidence of a carcinogenic effect; R22/Harmful if swallowed; R38/Irritating to skin. TBP is also listed as severely irritating to the eyes and respiratory tract in addition to the skin. [234] Triphenyl phosphate, a triaryl phosphate (TPP) with CAS number 115-86-6 which has a characteristic odour, does not carry any hazard levels or warnings in the Australian or EU databases. However it can be absorbed into the body by inhalation and effects of long-term or repeated exposure state *'The substance may have effects on the peripheral nervous system, resulting in impaired functions'*. [234] While Dibutyl Phenyl Phosphate is not listed in the main databases, the US Hazardous substances databank reports that it is associated with marked pain around the eyes and exposure to aerosolized or vapors of dibutyl phenyl phosphate formulations at high temperatures has been reported to produce nose and throat irritation accompanied by coughing and wheezing. 2-ethylhexyl 7-oxabicyclo[4.1.0] heptane-3- carboxylate (unidentified as a trade secret until recently) is an aliphatic epoxide that is not in the chemical databases, however the Skydrol MSDS uses a risk phrase of R 43 / may cause sensitization by skin contact. The additive 2,6-di-tert-butyl-p-cresol is reported to be irritating to the eyes and skin with long-term effects of repeated or prolonged exposure as it may cause dermatitis and may have effects on the liver. [234]

2.3.7 Deicing fluids

SAE Type 1, II, III or IV anti icing or deicing fluids are made to strict standards. These fluids are typically composed of ethylene glycol or propylene glycol with other ingredients including thickening agents, wetting agents, corrosion inhibitors and coloured UV sensitive dye. Type 1 deicing fluids are considered unthickened and provide short term relief as they flow off surfaces soon after use, while type II contain a thickening agent to prevent their immediate flow off aircraft surfaces. Type IV antiicing fluids are used after an aircraft has been deiced and provide longer holdover times. The fluids are used as a concentrate that must be diluted with water before use to varying specifications depending on conditions and requirements, or they can be formulated as a ready to use solution. Ethylene glycol based fluids have significant toxicity concerns, with Australian regulations listing the product as a *'harmful'* hazardous substance.

UCAR ADF 55/45 deicing fluid, as shown in Table 2-4, is a Type 1 propylene based ready to use fluid, containing ~53% propylene glycol and water or it can be formulated for use as a concentrate to be mixed with water. It is a hazardous substance based on its skin sensitizing and irritant properties.

Table 2-4: UCAR(TM) Aircraft Deicing Fluid Concentrate SAE/ISO Type I

Chemical	CAS	%
Ethylene glycol	107-21-1	92%
Non-hazardous processing additives	N/A	0.5%
Water	7732-18-5	7.5%

2.3.8 Combustion and Pyrolysis

An oil leak from an engine at high temperature or pressure may burn or be pyrolised before it enters the cabin air supply. [185] Little is known about the actual chemicals that enter the aircraft ventilation systems from the APU or the engines when the lubricating oils or other aircraft fluids have been heated in excess of 500 ºC and contaminate the air supply. At such temperatures pyrolysis of the contaminants can be expected, the result of which is a breakdown of the products that could have unexpected effects. [247] Exposures to such a complex cocktail are speculated to include CO_2, CO, partially burnt hydrocarbons (including irritating and toxic by-products such as acrolein and other aldehydes and TCP). [185] Studies more recently undertaken [248,249,250,251,252] confirm that heated engine oils do release a wide variety of chemicals, which are not part of the original ingredients in the oil. The current MJO II MSDS states that the *'Product may decompose at elevated temperatures or under fire conditions and give off irritating and/or harmful (carbon monoxide) gases/vapors/fumes.'* Pyrolysis studies of two jet engine oils at 525 ºC resulted in the release of CO_2 and CO (CO>100 ppm) as well as a large number of volatiles (not present in the oil itself) with TCP found both in oils as well as in the air. [253] Further pyrolysis studies of two hydraulic fluids and another jet engine oil showed that volatiles and organophosphate constituents were released in all cases, with engine oil being an important source of carbon monoxide. [247]

The airborne contaminants will be in the gas, vapour, mist and particulate form and such a cocktail cannot be dismissed without proper consideration. [185] Mists and aerosol particulates will settle under the force of gravity and where they coalesce or adhere to the surfaces, the concentration of the mist in the air would drop dramatically, leaving only a very low residual vapour, with only low levels of chemicals measurable. Therefore analysis of the air could underestimate exposure by orders of magnitude. [152] TCP and other oil constituents have low volatility and will condense, out of the air and remain airborne as aerosols or in association with particulate matter. [254] The focus on individual compounds does not take into account the presence of other agents that can alter the toxicity of a particular exposure, leading to a synergistic effect. [254] Oversimplification of a complex event may therefore ignore the true toxicity of an exposure. The effects of synergism, humidity and pressurisation have not been studied to the extent that suitable safe levels can be identified that incorporates these factors or identifies interaction between these factors. [255]

2.3.9 To Summarise

The oils, hydraulic fluids and deicing fluids used in jet aircraft operation contain a range of chemical substances at levels at which some are hazardous. While some of the constituents are available for review, others are not. Exposure to cold unheated oils and hydraulic fluids is an entirely different set of circumstances compared with exposure to the pyrolised and thermally degraded products that may contaminate the air supply to which crew and passengers are then exposed. In addition to considering whether the substances are in the gas/vapour phase as well as particulate, the type of airborne contaminants must also be considered as thermal degradation and pyrolysis can take place. There are a number of key additional factors that have not been considered when examining the toxicity of chemicals used within aviation environment. These include the uniqueness of the aircraft environment, the diversity and ages of passengers and crews who may be exposed to such products. Consequently, the focus needs to be on the overall toxicity of the combined, combustion and pyrolysed byproducts, which are released into the aircraft cabin specific envoronment along with some focus on selected individual contaminants. This is a necessary change from the current focus on individual chemicals or compounds present in the unheated original product.

2.4 The Mislabelling of Engine Oils

2.4.1 Introduction

In a similar manner to most countries, Australia has national model regulations that apply to all workplaces (when enacted by the States and Territories) in which hazardous substances are used or produced and in which employees are potentially exposed to the hazardous substances in those workplaces. [91] The objective is to minimise risk of adverse health effects due to exposure to hazardous substances by way of information provision, hazard assessment and control provision. The information required to be provided includes the provision of Material Safety Data Sheets (MSDS), an internationally recognised information source, which underpins the overall risk management program used to control exposure to hazardous and dangerous materials. In addition to the MSDS, specific labelling is required to be made available by employers to employees and other relevant authorities. The assessment and control provisions require employers to identify hazardous substances in the workplace, make an assessment of those substances arising out of the workplace activity and take appropriate action. Therefore the use of hazardous substances should be safe, provided the hazards are known, understood and appropriate actions are taken. [98]

The responsibility for the production and supply of the MSDS falls to the importer or manufacturer of the hazardous substance. It is their responsibility to determine whether the substance is a hazardous substance in accordance with the national guidelines. [91] In the Australian case the supplier is required to determine the hazardous nature of the substance being used from the *'List of Designated Hazardous Substances'*, now known as *'The List'*, or the *'Approved Criteria' for classifying hazardous substances'.* [91,94]

The classification categories are shown in Table 2-5.

Table 2-5: Hazardous Substances Classification Categories

Does not meet criteria for harmul or hazardous	Not hazardous		Type III
Meets criteria for harmful or irritant but not toxic	Hazardous	Harmful	Type II
Meets criteria for toxic or very toxic		Hazardous	Type I

It is seen in this classification, that the category of harmful is classified as hazardous.

The MSDS must be reviewed from time to time and must be made available by the supplier before or upon initial use of the product, or following a legitimate request. The supplier must ensure all containers of hazardous substances used at work are appropriately labelled. Additionally, the supplier must provide the employer with any other relevant information in addition to that contained in the MSDS which will assist in the safe use of the substance. [91]

The Australian classification criteria are adopted from the European Community's (EC) legislation for classifying dangerous substances. The specific Directives are the EC Council Directive 67/548/EEC and the Directive 1999/45/EC of the European Parliament and Council 1999. [102,103] In 2009, Regulation (EC) No 1272/2008 [105] on classification, labelling and packaging of substances and mixtures was introduced, implementing the Globally Harmonised System (GHS). The new legislation will *'will stepwise replace Directive 67/548/EEC (substances) and Directive 1999/45/EC (preparations)'* over the period December 2010 and mid 2015. [106]

The EC legislation under the direction of the former European Chemicals Bureau is seen as the international standard from which most other countries will take their guidelines and legislation from. [102,103,105] Not only are the Australian *'Approved Criteria'* taken from the EC directives, [94,102,103] but additionally, the Australian *'List'*, now known as the Hazardous Substances Information System (HSIS) is adopted from the European chemical Substances Information System (ESIS), an internet based system encompassing the various EC chemical databases. [96,104]

A chemical formulation (or individual ingredient) being supplied to workplaces should be assessed correctly against the List, and if not present on the list, to the relevant *'Approved Criteria'*, and if classified as hazard, must provide hazard communication in the form of a label on the container and an MSDS. The label of a hazardous substance should comply with the Labelling Code and the MSDS should comply with the MSDS Code, both of which provide advice on safe handling and use of that chemical. The advice contained on the MSDS includes the chemical and physical properties of a material, information on health effects, exposure control, safe handling and storage, emergency procedures, and disposal. A flaw in the MSDS philosophy is that the product manufacturer produces the MSDS and these are generally not reviewed independently as it is the product manufacturer or importers responsibility to produce these and they are simply submitted to the authorities, but not reviewed to ensure the requirements are met.

Under the Occupational Health and Safety guidelines that exist in various countries, certain substances are classified as hazardous, because of known toxicity or other properties. Further, because not all such chemicals are hazardous at low concentrations in formulated products, they may be assigned a content value above which the substance is deemed to be hazardous with further sub categorisation such as 'harmful' or *'toxic'*. These warnings should then be placed on a label on the product's container and MSDS.

In order to correctly classify a mixture, there are two methods that can be used. A mixture can be tested as a whole with the health effects then assessed using the *'Approved Criteria'*. Alternatively if the mixture has not been tested as a whole, each ingredient of the mixture must be assessed against the 'Approved Criteria' or using *'The List'*, formerly titled the *'List of Designated Hazardous Substances'*, with *'The List'* being the initial place to review. [91,92,93,94,96, 104] If a substance is on *'The List'*, it is considered a hazardous substance, while if not on *'The List'*, a determination of the hazardous nature of the substance must be made by reference to the 'Approved Criteria'. [91,94] If a substance is not on *'The List'* it may still be hazardous to human health but has not yet been classified. [94] Information on health effects can be obtained from a variety of sources including: scientific reference works and literature, practical experience such as the health effects of the substance on exposed persons and results of experimental animal testing. [94] Importantly if evidence is available to show that in practice, the toxic effect of a substance on humans, is or is likely to be different from that suggested by animal testing, then the substance should be classified according to its human toxicity. [94] The parent UK Directive and US regulations also require the use of human data where available, with human data taking priority in the UK and US case. [103,256] Additionally, the classification of a substance may need to be revised periodically as new information becomes available. [94]

Two of the chemicals of particular interest in the oils are tricresyl phosphate (TCP) and N-Phenyl-alpha-naphthylamine (PAN). An assessment of present and past labelling used for Mobil jet Oil II (MJO II) will be examinded to provide an example of the labelling and MSDS issues of concern. Mobil has advised that it's assessment of MJO II as *'not hazardous'* is based upon testing the product as a whole as well as it's own review of scientific studies, including it's own internal and published testing. [183,184,215] However, an independent assessment is required to determine the actual classification of MJO II and subsequent MSDS and labelling that is use today.

2.4.2 MSDS Assessment of MJO II

An MSDS is required to list various substances under section 2 regarding *'reportable hazardous substances'.* The current US and EU MJO II MSDSs list TCP in the oil at up to 1-3%, (known to be 3%), using a CAS number of 1330-78-5 as well as PAN with CAS of 90-30-2 at 1%. The Australian MSDS lists TCP only at 1-3%, also known to be 3% in the oil, however PAN is not listed. With regards to TCP, the Australian MSDSs list risk phrases of R21/22, harmful by skin contact or if swallowed respectively, while the US MSDS fails to list either of these risk phrases. With regard to PAN on the EU and US MSDS's, the risk phrase of R22 (harmful if swallowed) and Xi R43, used for the *'sensitizing/irritant'* properties which *'may cause sensitisation by skin contact'*, is listed on the EU version only.

TCP as a blend of ten isomers using CAS 1330-78-5 is not listed on the European or Australian hazardous substances databases. [96,104] However Mobil advised that the concentrations of all the triaryl phosphate isomers were computed by statistical procedures from the compounds in the hydrolysates with the various phenols and xylenols having virtually the same reactivity. [183] Therefore Mobil stated that the TCP in MJO II contains 3076 ppm or >0.3% (1% or 10,000ppm) of ortho-cresyl phosphate (OCP) isomers of TCP, a known neurotoxin. [183,226] With TCP in the oil at 3%, the level of ortho isomers would be deemed by many to equate to less than 0.01% (93ppm) in the oil. However, the equivalent toxicity of the OCP isomers has been significantly underestimated by a factor of up to 30,731. [182] This is due to the very common practice of sole reference to the least toxic of the OCP isomers, Triorthocresyl phosphate (TOCP), while excluding the higher quantities and toxicity of the other OCP isomers, MOCP and DOCP. [182] TOCP has been deemed *'an appropriate surrogate'*, despite it not being the most toxic of the isomers, yet the studies undertaken have focussed on TOCP and it has been known for 40 years [257] that the other OCP isomers of TCP (MOCP and DOCP) are more toxic than TOCP and that reference must not be made to TOCP alone. [226,238,257] The levels of all the OCP isomers and the equivalent toxicity should be taken into consideration on the regulatory classification of materials containing TCP. [227] Therefore, the equivalent toxicity of the OCP isomers in the oil with TCP present at 3%, is 931 ppm (30731 ppm/33) or less than 0.1%.

The OCP ortho isomers of TCP, using CAS 78-30-8, are listed on the EU and Australian hazardous substances databases. [96,104] It is noteworthy that the OCP isomers (TOCP, DOCP, MOCP) on these lists referred to under the CAS number 78-30-8, are termed tricresyl phosphate, triorthocresyl phosphate, tritolyl phosphate or tri-o-tolyl phosphate. This supports the findings that the other more toxic OCP isomers of TCP, other than TOCP have been ignored, with TOCP assumed to be acceptable as a surrogate, despite the fact it is ten times less toxic than MOCP and five time less than DOCP. [182,226,257] However any substance (in the final product) on the hazardous substances *'List'*, above the given levels is considered a hazardous substance, with 'The List' being the first document to consult. [92,93,94] The OCP isomers in the TCP (>0.3%) are classified as toxic with hazardous substance *'harmful'* classification at a concentration between 0.2% and 1% with risk phrases of R68 and R20/21/22: *'possible risks of irreversible effects'* (non lethal after single exposure), *'harmful by inhalation', 'harmful in contact with skin'* and *'harmful if swallowed'* respectively.

However, when considering as required the OCP content in the oil using the toxic equivalent level of 931 ppm or <0.1%, the classification by *'The List'* becomes non-hazardous/(non) harmful. As such it is necessary to review the health effects against the *'Approved Criteria'*. By referencing the hazardous substances *'List'* as well as the internationally accepted International Chemical Safety Cards (ICSC) and NIOSH Chemical Guides, [234,258] Risk Phrases R68 (possible risks of irreversible effects) and the risk phrases for the three main routes of exposure, R20/21/22 are applied. As such the OCP isomers, dependent on levels, could necessitate a hazardous/harmful classification. In the case of MJO II, the concentration of OCP isomers in the oil (<0.1%) would be classified as non hazardous as they fall below the 1% cut off level *('Approved Criteria'*, Table 1 or European equivalent from where the Australian levels are sourced) for a substance warranting a harmful classification. [94,103]

Additionally, substances with similar health effects can have additional, potentiation or synergistic effects, even though in the product at below the given concentration cut off levels. [94] As such the Listed levels (1% in this case) '*are designed to provide a practical level of protection and should not be used to imply that an effect cannot occur below that level.'* [94] While the *'Approved Criteria'* provide a formulae for the use of additive effects, no such advice is available for synergistic or potentiation effects. The US Navy Toxicology Unit in the early 1960s, when investigating long-term continuous inhalation to triaryl phosphates (tricresyl phosphates, trixylenyl phosphates and other trialkyphenyl phosphates), found it '*highly suggestive that components other than the ortho tolyl (OCP) groups have significant paralytic activity or are capable of synergizing or potentiating the toxic effect of triaryl phosphates.'* [259] This is supported more recently with recognition that in addition to the neurotoxic properties of the ortho cresyl isomers, the toxicity of the other chemically similar OPs such as xylenols and phenolics, present in the TCP as contaminants, would add to the relative toxicity of the ortho TCP content, [182] while the non ortho isomers of TCP are no longer considered to have no toxic effects. [260, 261] In 1958 it was known that the meta and para isomers of TCP cause the formation of mono-ortho and di-ortho esters with the toxicity of the mixed esters being much greater than pure TOCP. [257]

The non ortho isomers of TCP must also be referenced against the hazardous substances *'List'* and *'Approved Criteria'* to determine their classification as they are known to represent approximately 99% (> 99% Mobil [183]) of the TCP in the oil, in either tri-para, tri-meta or mixed meta and para isomers which equates to a level of approximately 2.97% in the oil. [231,232] These meta and para isomers of TCP are classified as harmful via skin absorption and ingestion at levels above 5% in the oil. As such the meta and para isomers are not technically classified as hazardous. However, once again the synergistic properties of the non ortho isomers with the other triaryl phosphates would need to be considered and research now states the non ortho isomers may not be non-toxic as previously assumed. [260,261] At levels above 2.5% the non ortho isomers must carry R52 and R53, '*harmful to aquatic organisms'* and *'may cause long-term adverse effects in the aquatic environment'*. The EU MJO II MSDS lists these risk phrases or higher against TCP, while the Australian MSDS does not.

The OCP isomers in the TCP in the oil are technically classified as non hazardous according to the EU and Australian guidelines, given the synergistic effects and borderline quantities of OCP isomers and high content of non ortho isomers. However, it would be prudent to review the risk phrases that ought to be used if a hazardous classification of TCP OCP isomers was deemed necessary. Chemtura, one of the two global TCP manufacturers advised that TCP is classified as harmful according to EU regulations. [196] The International program on Chemical Safety (IPCS) and NIOSH list that short term effects of inhalation, skin absorption or ingestion of OCP isomers may cause effects on CNS/PNS and exposure above the occupational exposure limits (OEL) may lead to degeneration of the nervous system. [230,258] Additionally, they list effects of long-term or repeated exposure as maybe having effects on the nervous system. These statements would necessitate not only the use of risk phrase R68 ('*possible risk of irreversible effects'* based on non lethal irreversible effects after single exposure) but also R48 used where severe effects after repeated or prolonged exposure could lead to '*danger of serious* *damage to health by prolonged exposure.*' [94] The Australian and EU hazardous substances *'Lists'* refer to R20/21/22 (all routes of inhalation) as well as the single exposure risk phrase (R68) associated with possible irreversible effects, however they fail to list R48 required for repeat or prolonged exposure. [96,104] Additionally, the EU and Australian MSDSs list only Risk phrases of harmful by ingestion and skin absorption and ignore inhalation and the short and long-term irreversible damage phrases entirely (R68/48), while the US MSDS fails to list any of these. However, as stated, given the non hazardous classification of the OCP isomers in the oil, without correctly looking at the synergistic effects and the high content of non OCP isomers and updated toxicity data, this could be deemed acceptable.

With regard to R48 covering repeat or prolonged exposure, this should be applied not only where there are severe changes in a single organ or biological system but also with *'generalised changes of a less severe nature involving several organs, or severe changes in general health status'.* [94]

Given the internationally accepted IPCS and NIOSH databases and human data available on exposure to synthetic jet engine oils containing TCP, a review of the hazardous substances lists is warranted. The need to revise the classification of substances may be needed periodically as new information becomes available. [94] The recognition to revise data as new data become available from a variety of sources including data from occupational disease sources and case studies, likewise underpins the lead European system. [103] Additionally, where effects such as potentiation (and synergism) show conventional toxicological classification could underestimate the toxicological hazard, such effects must be taken into account. [103]

MJO II MSDSs have and continue to use the CAS number 1330-78-5 for TCP. This is the CAS number used to cover all ten isomers of TCP, but does not identify the breakdown of isomers into meta-, para- or ortho- types. While this CAS number was listed on the Australian hazardous substances list up until 1999, [262] it was then withdrawn (in line with the European list) in favour of the current CAS numbers that identify the ortho and non ortho isomers, 78-30-2 and 78-32-0 respectively. As such, 1330-78-5 should in fact no longer be used on MSDS as it fails to identify the various isomers. [93,94,96,104,182] The inappropriate use of the 1330-78-5 CAS number for TCP was recognised by the UK Health and Safety Executive who stated the use of this CAS number was *'slightly misleading'*. [263] Notably CAS 1330-78-5 can still be found on US Department of Transport databases, however it is not listed by NIOSH, OSHA or the EPA. [264,265]

The failure to meet the occupational health and safety notification of hazardous substances is particularly concerning given the breakdown of ortho and non ortho isomers is known, even if not widely made available. [183] It could be assumed the use of the old CAS number 1330-78-5 is still used today so as to not identify TCP ortho isomers; [182] or a denial of the hazards and risks and therefore a way of not having to adhere to the obligations outlined when dealing with hazardous substances in the workplace. While TCP was advised as a load carry*ing additive at a government inquiry, a 'proprietary metal passivator ~ 0.2%'* was also listed. [216] Given that TCP is a metal passivator, [266] it would appear the 0.2% referred to is the OCP content and therefore seen as *'proprietary'.*

When looking at the previous use of the TCP CAS 1330-78-5 prior to 1999 which covered all isomers, the product was listed as in the oil at 'toxic' hazardous levels. With TCP at 3% in the oil, it was well above the 1% level where the substance was classified as *'toxic'*. [262] This automatically required the risk phrase of R39, *'danger of very serious irreversible effects'* in the category of non-lethal irreversible effects after a single exposure. R23/24/25 were also to be applied as toxic by inhalation, in contact with skin and by ingestion.

In summary TCP in the oil at 3% containing >0.3% OCP isomers (of which the majority is MOCP) using the toxic equivalents approach indicates the OCP isomers are in the oil at just under 0.1% and could be seen as not hazardous/ *'harmful'* as they are under the 1% cut off level. However, synergistic effects are highly likely and should not be ignored, nor should the inhalation toxicity of the non ortho isomers of TCP. It is also inappropriate to use the old CAS 1330-78-5 that does not identify the isomer breakdown, however in the past, such usage would have required a hazardous 'toxic' classification. The long-term effects of the ortho isomers should be taken into account and the inhalation toxicity data of all isomers of TCP should also be revised as it has all but been ignored except for the initial 1950's USAF and 1960s US Navy studies and these studies did not indicate there was no risk.

N-Phenyl-alpha-naphthylamine (PAN) with CAS of 90-30-2 in MJO II at 1% is not included on the hazardous substances list, however it is clearly classified as a hazardous substance based on it's properties as an irritant (Xi) based upon it's skin sensitization properties, necessitating R43. Substances classified as a sensitiser or irritant in a mixture at or above 1% are considered a hazardous substance. [94,103] As such PAN definitely at 1% in the oil meets these criteria. While short-term exposure may cause effects on the blood, resulting in formation of methaemoglobin, long-term or repeated contact may cause skin sensitisation. [234]

The other substances in MJO II, while technically not hazardous, of course add to the mix and should not be ignored. B- napthalenamine (CAS 91-59-8) is a contaminant of PAN and is in the oil at very low levels (0.00005%), well below the hazardous classification levels of 0.01% by *'The' List*. However it is listed as a schedule 1 category 1 carcinogen with R45, may cause cancer or known to be carcinogenic to humans. [96,104,234] Therefore as a contaminant in an industrial process, it should be strictly controlled to prevent worker exposure, [95] while NIOSH recommends to *'Avoid All Contact!'*

Given that MJO II contains PAN, which is without doubt in the oil at hazardous levels based upon the use of the *'Approved Criteria'* and European equivalent, MJO II based upon NOT testing the product as a whole, contains a hazardous substance and therefore MJO II is classifiable as hazardous. While it could be argued that the ortho isomers of TCP and the high content of the non ortho isomers, should be classified as hazardous in the oil, there is no question with PAN. The inclusion of PAN at 1%, MJO II as a mixture is classifiable as a hazardous substance according to the guiding European classification criteria and consequently Safe Work Australia criteria.

However, the MJO II MSDSs for at least Europe, US and Australia currently list the MJO II as *'not hazardous'* according to their respective regulatory guidelines. Specifically they advise the product is not hazardous according to the *NOHSC 'Approved Criteria'* in the Australian case, the *'EU dangerous* *substances/preparations Directives'* in the European case and the *'OSHA Hazard communication standard'* in the US case. [267] Interestingly the US MSDS advises the material is not classified as hazardous in accordance with OSHA 29 CFR 1910 1200 *'when used for its intended purpose'.* [267] Mobil has advised that it does not consider oil leaking into aircraft cabins is *'normal use'*.

- *'We do not believe jet turbine oils pose any significant toxicological risk to individuals accidentally exposed to aerosols or vapours in aircraft cabins. Such exposures are not what we would refer to as 'normal use' but the cabin levels that can be reached during such exposures comprehended by our internal and published risk assessments and are considered safe.'* [183]
- '*Mobil do not consider accidental exposure to oil vapours in an aircraft cabin to be 'normal use.'* [184]

As stated previously it is possible to test a mixture in 2 differing ways. Either it can be tested as a whole and then referenced against the *'Approved Criteria'* or EU Directive, or as is more usual, the individual substances, particularly where data about them are known, are referenced against *'The List'* or *'Approved Criteria'* or EU equivalent. Mobil has advised it has based it's classification of the product on the fact it was tested as a *'whole'*, and that it's own internal and published assessment of the product as whole and a review of the individual substances meet the hazardous substances *'Approved Criteria'* and EU Directive. [183,184,215,268] However as shown above when using the *'Approved Criteria'* method reviewing the individual substances, MJO II is classifiable as a hazardous substance. Assessment as a whole cannot be independently assessed, apart from a review of the publicly available studies as far back as at least 1988. [226,238,241,269,270,271,272,273]. While these studies were all undertaken in conjunction with Mobil, Mobil advises that toxicological testing has shown that MJO II is *'not acutely toxic via inhalation, ingestion or dermal absorption and is not a skin or eye irritant.'* [268]

However the Mobil studies, utilised as part of it's assessment of the product as a whole, do not utilise the appropriate route of exposure. Later studies which were undertaken by ExxonMobil in conjuction with M. Ehrich of Virginia Tech (unpublished) in 2002/2003 involving hens administered Mobil Jet Oils orally, led ExxonMobil to reclassify its toxicological assessments downwards.

[274,275] This study involving chickens orally given cold MJO254 and TOCP was subsequently published as an abstract only in 2006. [276] The various internal and published Mobil studies show that the studies involved animals either ingesting or exposed dermally to the cold product with reference to the OPIDN form of neurotoxicity only. Inhlation studies have not been undertaken using the cold or heated oil. In fact Mobil had previously confirmed its narrow definition of the possible toxic effects as follows:

- *'Transient gastrointestinal effects and OPIDN are the only toxic effects that we accept as being caused by human exposure to TCP.'* [277]
- *'OPIDN is the only neurological disorder that we believe could potentially be caused by very high exposure to Jet Oil II, most likely through ingestion.'* [214]

The only inhalation studies known to have been undertaken on the oils or triaryl phosphates were conducted by the USAF and US Navy in 1954 and 1965, yet again, at atmospheric conditions on animals, with results indicating concern and toxicity. [146,147,259] Mobil has advised that it would be virtually impossible for a person to inhale or absorb enough JEO II exposure (TCP 3%) in an aircraft to cause OPIDN and that it has no record of JEO II causing human neurotoxicity (OPIDN). [183,226,278] There has been heavy criticism that Mobil/ExxonMobil is well aware of human ill health associated with exposure to jet engine oils ranging back many years. The awareness is not limited to a letter of complaint provided to OSHA that led to a citation against ExxonMobil that was later settled. [275]

When questioned about inhalation toxicity studies undertyaken by ExxonMobil or Mobil, it advised that over the years many studies had been undertaken and specifically it's 2003 study undertaken in conjunction with Virginia Tech had orally dosed hens so as to *'maximise systemic exposure'.* [273] ExxonMobil went on to advise that:

- *'As there were no adverse effects under this severe exposure condition the data obtained suggest that occupational exposures by dermal or inhalation routes would not be associated with the risk of OPIDN either.'* [273]

While Mobil has clearly tested it's product as a whole on animals and referenced the health effects against scientific literature animal data, it has ignored all human evidence. The *'Approved Criteria'* clearly state that information can be obtained from a variety of sources in addition to animal experiments, such as practical experience and the health effects of the substance on exposed persons. [94] The US OSHA regulations require that where case reports of adverse human effects are available, such data *'shall'* be considered in the evaluation. [256] Additionally, where there is evidence that human toxicity may be different to animal studies, the human data are to take priority. [94,103] While it is well acknowledged that jet engine oil is known to leak into aircraft cabin air, including by Mobil, and that human adverse effects are occuring, these human data have been inappropriately ignored by Mobil. Additionally, and most importantly, in order for corporate studies of its product as a whole to be accepted, the studies would need to be undertaken using the method relevant to the occupational exposure. The studies used by Mobil include oral as well as dermal exposures with the later possibly applicable to engineers handling the product. However these exposures are totally inappropriate for inhalation exposure inside the cabin, even though some dermal exposure would still be expected to occur. As such, the testing undertaken as a whole is inapplicable, as the wrong exposure route has been used and the thermal changes due to the heating of the product have also been ignored. [275,279] The former principle toxicologist for Mobil advised: [280]

- *'Of course the oils have not received the same amount of testing as a drug would receive because they are not meant for high dose long term human exposures and are, in effect, overlabelled for the worst possible effects imaginable... the market for the oil is very small for a large company to pursue... The profit on this product is not high enough to support a very expensive research program by the oil manufacturers and little would be lost to a manufacturer by simply dropping the product.'*

The quality of a hazard communication program being clearly dependent on the accuracy of the hazard determination is recognised by OSHA. [256] However chemical manufacturers, importers and employers are not required to follow any specific methods for determining the hazards, but must be able to demonstrate that they have followed various criteria to determine any hazard. These include the requirement to consider human data along with case reports of adverse health, the use of animal data, given human data is not generally available and the findings of scientifically valid studies which tend to refute the findings of a hazard. This process is noted to rely heavily on the professional judgment of the evaluator, particularly in the area of chronic hazards, but all that is required is a scientifically defensible evaluation. [256]

In 1999 Mobil advised NOHSC, the Australian regulatory authority, on how it had classified MJO II as '*a non hazardous product*' based on the *'Australian Approved Criteria for classifying hazardous substances'* and the EU directive. [94,102,103,262,268] NOHSC responded by advising Mobil that in order to clarify the derivation of the statement '*not hazardous by Worksafe criteria'* the words '*as determined by Mobil, based on toxicity test data on the product*' should be added to the statement. [281] NOHSC advised this would avoid any confusion as to the source of the statement, and clarify the use of the (Mobil) test data as the primary source in preference to the standard use of the NOHSC *'List of Designated Hazardous Substances'.*

The level of confusion, even by the regulatory authority, is best evidenced in an overview by NICNAS, a division of the Australian Commonwealth Department of Health, when reviewing the individual ingredients in MJO II. [282]

When reviewing the hazard of MJO II as a whole, NICNAS advised the *'Approved Criteria'* stated the product could be tested as a whole (method used by Mobil) or classified based on the health effects of the individual ingredients. [282] The NICNAS overview, then inappropriately only referenced the individual substances against the *'list of designated hazardous substances'* and failed to assess the ingredients against the *'Approved Criteria'*. It therefore indicated no substances were on *'The List'* above the cut off classification levels. However PAN at 1% is a skin sensitiser/irritant and as such is classifiable as a hazardous substance based on the *'Approved Criteria'*. However the NICNAS overview, when looking at the classification of the product overall, incorrectly ignored the *'Approved Criteria'* method. The failure of the regulator to advise Mobil that, based upon the *'Approved Criteria'* and use of the individual substances method, MJO II would be classifiable as a hazardous substance is noteworthy.

[283] Instead the regulator allowed Mobil to support it's *'non hazardous'* view, given that Mobil had assessed the product as a whole based on it's own testing and simply advised Mobil to report it's own work as the source of the statement.

Given that human data of the effects of exposure have been ignored and testing undertaken of MJO II as a whole had been undertaken in a manor that ignored the primary exposure route, it IS appropriate to list MJO II as a hazardous product given the PAN concentration assessed against the *'Approved criteria'.* Therefore, the MSDS used for this oil in Australia, the EU and US is inappropriately formatted. Under the Australian guidelines, the MSDS for MJO II is required to list a statement of the hazardous nature. In this case it ought to contain the wording *'HAZARDOUS SUBSTANCE'* and it is deemed useful to describe how this was determined: *'classified as hazardous according to the criteria of NOHSC'*. [98] All 3 MSDS's list the product as not considered hazardous. PAN is then required to be listed as a reportable hazardous substance with at least the risk phrase Xi R43 and possibly R20/21 in addition to R22. Importantly all ingredients *'may'* be listed, even if they are not hazardous substances, as they may contribute to the effects of the material and in the case where synergistic effects are known to occur, the ingredients *'should'* be listed. [98] As such, while TCP is technically not in the oil at hazardous levels it should be listed on the MSDS as TCP *'may'* contribute to the overall effect and is thought and known to have synergistic effects with other the other triaryl phosphate esters and pesticides respectively. [259,260,284] Again given the controversy over the TCP isomer breakdown, TCP if above the cut off level and given it has an exposure standard (even though it is inappropriately used as it covers TOCP only), would be deemed a Type I ingredient for which full disclosure is required on the MSDS (see Figure 1-8). The Australian MSDS incorrectly fails to list PAN but does list TCP, while the EU and US MSDS list both TCP and PAN, but the later fails to list the risk phrases. All 3 use the incorrect TCP CAS number of 1330-78-5. The MSDS is also supposed to list any applicable exposure standards. While the TOCP exposure standard of 0.1 mg/m^3 cannot be applied to the whole TCP content, the intent of the exposure standard should be listed and as such the exposure standard requires revision. Additionally health effects data are in some cases limited. PAN is listed as a skin sensitiser, however it is also listed as skin, eye, and mucous membrane irritant as well as leading to the formation of methaemoglobin in the blood. [258,285] Exposure by inhalation may cause respiratory irritation with sore nose, sore throat, and cough. It is also listed under the class of tumorigen and mutagen on the RTECS database.

The current MSDSs state under the hazard identification: [267]

- *'This product is not expected to produce adverse health effects under normal conditions of use and with appropriate personal hygiene practices. Product may decompose at elevated temperatures or under fire conditions and give off irritating and/or harmful (carbon monoxide) gases/vapors/fumes. Symptoms from acute exposure to these decomposition products in confined spaces may include headache, nausea, eye, nose, and throat irritation.'*

However, between 1997 and 2004 the MSDSs carried health hazard data stating:

- *'Effects of overexposure: This product is not expected to produce these effects under normal conditions of use and appropriate personal hygiene practices. This product contains tricresyl phosphate (TCP). Overexposure to TCP by swallowing, prolonged or repeated breathing of oil mist, or prolonged or repeated skin contact may produce nervous system disorders including gastrointestinal disturbances, numbness, muscular cramps, weakness and paralysis...'*

However Mobil has identified it does not regard leaking oil into an aircraft air supply as 'normal' conditions of use. [183,184] As such the MSDS does not cover abnormal usage and in the US case, the product classification of not hazardous is inapplicable as oil leaking is not an *'intended use'* and is foreseeable.

The major change by way of the deletion of the neurological references in connection with TCP and inhalation exposure are of interest. In 2004, the Association of Flight Attendants in the US advised OSHA of their concern that ExxonMobil had removed the warnings and described this action as *'highly inappropriate'*. [275] OSHA issued a citation against ExxonMobil for the removal of the warnings on the MSDS of MJO II, MJO 254 and MJO 291 and applied a penalty of US$1700. [286] ExxonMobil contested the citation applied by OSHA as well as the penalty. [287] Almost a year later ExxonMobil came to a settlement in its case against OSHA and the citation was withdrawn. [288] As a part of the settlement ExxonMobil agreed to put on it's MSDS for MJO II, 254 and 291: [288]

- *'A literature report of a generic jet engine oil containing tri-cresyl phosphate (TCP) with concentrations of ortho-phenol isomers well in excess of those found in this ExxonMobil product noted delayed peripheral nerve system damage in test animals. A current study of an ExxonMobil Jet Oil formulated with a relatively low ortho-phenol isomer content produced no peripheral nerve system damage in test animals.'*

ExxonMobil added the above statement in the chronic/other information section of the MSDSs. The MJO II MSDS also added that *'oral exposure of male rats to a lubricant formulation with 3% TCP resulted in no adverse reproductive effects'* and *'contains: Phenyl-alpha-naphthylamine (PAN): Undiluted PAN is a skin sensitiser. Human testing with lubricants containing 1.0% PAN caused no reactions indicative of sensitisation'.*

Failure to justify the removal of the references to the potential neurological damage was raised along with the new warnings of carbon monoxide exposure understating possible effects. [275] In addition to the direct MSDS references to TCP effects being removed, the note to physicians about TCP and possible cholinesterase inhibition was also removed.

While tests again undertaken on animals orally exposed to TCP were said by ExxonMobil to cause no adverse reproductive effects, another oil manufacturer has recently upgraded its warnings on its MSDS. [223] The revised risk phrases include: R62/F3; Possible risk of impaired fertility and R63/G3; Possible risk of harm to the unborn child. The studies undertaken reviewed TIPP in addition to TCP and TOCP used in commercial jet oils and found adverse effects in both products. [222] TCP alone was shown to be a reproductive toxicant. [289] While ExxonMobil reports that human exposure to oils containing PAN showed no sensitisation, other studies showed PAN to be a strong skin sensitiser in both guinea pig studies as well as case studies in exposed workers. [290,291,292,293]

During the period up to 2004 the MSDSs for MJO II varied considerably, both in terms of hazard classification, listed substances, hazards and risk phrases utilised. The Australian MSDS has consistently stated the product was not hazardous except in 1995 when it carried the statement *'Harmful by Worksafe criteria.'* The US MSDS from at least 1995 to 2004 stated *'Product assessed in accordance with OSHA... and determined to be hazardous'*. The EU MSDS in 2004 stated *'This material is considered to be hazardous according to regulatory guidelines.'* Mobil advised in 1999 that it had been an error to list MJO II (in the Australian case at least) as hazardous, [183] however as stated the hazardous warning remained in the EU and US until 2004. Prior to 1997, the emphasis had been placed on ingestion only and Mobil advised it's studies showed OPIDN was not possible from an exposure to it's oil in an aircraft, it was possible to cover the entire body in MJO II for six hours and a neurotoxic dose was only possible by very high rates of ingestion in animal studies. However in 1997 Mobil changed the MSDS and labelling to include inhalation and dermal exposures as a *'conservative approach only.'* [183] Additionally, the 1992 MSDS inclusion of B- napthalenamine and the other contaminants of PAN were removed in later MSDS revisions as the inclusion of these contaminants at low levels was considered to raise undue public concern and was not considered meaningful information. [215]

In addition to the MSDSs for MJO II varying over the years, the oil can warning labels have followed a similar varying pattern. Up until around 1998, the label warned that TCP could cause paralysis if taken internally. In 1998 Mobil upgraded the warnings to include the previous warnings on ingestion as well as:

- *'Warning! Contains Tricresyl Phosphate*

  Prolonged or repeated breathing of oil mist, or, or prolonged or repeated skin contact can cause nervous system effects. Avoid prolonged or repeated overexposure to skin or lungs.'

At some stage after 2004, the label was changed to include the fact that PAN was a substance that *'may produce an allergic reaction'* with the continued TCP warning referring to repeated breathing and nervous system effects. Some time after 2005 all TCP and PAN warnings were removed from the MJO II label with new wording stating:

- *Mobil Jet Oil II*

  Helps control deposits, keeping gas turbine engines cleaner and operating more efficiently;

  Has a history of providing trouble-free performance;

  Used exclusively in the engine that holds the record for the longest "on-wing" time;

  Can mean less maintenance, more flying and greater revenue for your fleet.

As MJO II should be listed as a hazardous substance, the above labelling does not follow the NOHSC guidelines and therefore fails to identify to the user what the substances are and what significant hazards may be involved. [91,98]

Figure 2-11: Mobil Jet Oil II labelling

The labelling requirements closely follow the MSDS requirements. It is noteworthy that the cardboard packaging that the cans of oil are delivered in states the product contains Tricresyl Phosphate (1330-78-5); 1-Napthalenamine, N Phenyl (90-30-2); Alkylated diphenyl amines (68411-46-1); Proprietary ester and additives. The previous label contained at least some of the required warnings and the size of the container does not warrant the label excluding the contents and necessary warnings, deferring to the cardboard packaging (see Figure 2-11 on previous page).

Clearly, ExxonMobil has looked at the toxicity of MJO II in terms of delayed neurotoxicity (OPIDN) from (drinking/dermal) exposure to the cold oil. Synergistic exposure or the effects of inhaling heated engine oils in a reduced pressure environment have been ignored. Potential effects from inhaling heated oil fumes such as respiratory illness, chronic neurotoxicity (OPICN) or any impact on gene expression as result of exposure have not been investigated.

The hazard classification is inappropriate as is the MSDS layout. This results in the end user not being provided with all necessary and appropriate information.

2.4.3 Information supplied for other products

While not attempting to analyse all MSDSs and labels for other oils and hydraulic products, similar problems appear to exist for other products. The 2006 Australian MSDS for BP 2380 Turbo Oil will likely contain TCP and PAN to similar levels as MJO II as it has to meet the same standards. However the MSDS fails to list TCP or PAN at all and merely states it contains synthetic base stock and *'proprietary performance additives...'* It is the user's obligation to evaluate and use this product safely and to comply with all applicable laws and regulations. However BP advised a Government inquiry that its oil contained TCP and mixed aromatic amines, including PAN, both at 1-5%. [216] The German 2008 BP 2380 MSDS advises TCP with CAS 1330-78-5 is in the oil at 5-10% with PAN (CAS 90-30-2) in the oil at 1-5%, however not with a hazardous classification yet PAN may cause an *'allergic reaction'*. The 2001 UK BP 2380 MSDS advised that the ortho isomers of TCP were less than 0.1% (MJO II <0.3%) of the TCP in the oil with TCP at levels of <3%. The US BP 2389 MSDS, while not reporting any hazardous ingredients, states that the product may cause eye, skin or respiratory tract irritation. The Australian Aeroshell Oil 500 lists TCP at 1-2.4% under CAS 1330-78-5 along with PAN at 1-2% and interestingly states *'Hazardous substance - Hazard classification according to the criteria of NOHSC'.* Skin sensitisation is listed under the human health hazards as well as neurological warnings with possible permanent effects. The toxicological information is derived from the *'knowledge of the components and the toxicology of similar products.'* The Aeroshell MSDS unlike most others advises the base stock is a *'Synthetic ester blend with pentaerythritol.'*

The MSDS for Turbonycoil 600 lists the product as not hazardous by Directive 1999/45/EC. [103] TPP and TIPP are listed on the IUCLID databases, however neither are listed on the EU or Australian chemical hazards database apart from TPP on the Australian system as it has an exposure standard. The absence of the chemicals on the list does not indicate they are necessarily non hazardous. Long term or repeated exposure to TPP by inhalation *'may have effects on the peripheral nervous system, resulting in impaired functions.'* [258] While TIPP is listed at a concentration in the oil *'below the minimum danger threshold'*, it does carry risk phrases related to fertility and harm to the unborn. However the MSDS does list risk phrases relating to the unborn and infertility based on internal research undertaken. [222]

The various hydraulic fluid MSDSs such as Skydrol LD 4 and ExxonMobil Hyjet IV-A Plus are listed as hazardous substances with varying risk phrases including irritating to the skin and eyes, skin sensitiser, category 3 carcinogen and in the former case, risk of very serious damage to the eyes. However the data sheets would have to be closely examined to assure their accuracy.

2.4.4 To Summarise

In conclusion, without adequate hazard identification, the correct information will not be supplied to the user of the products. Without the correct information, appropriate assessment and control measures, such as risk assessments and health monitoring cannot be provided in the workplace and exposure to a hazardous product, which should have been avoided, may lead to adverse health and safety effects.

2.5 The Exposure Standard Debate

2.5.1 Introduction

Exposure standards or Threshold Limit Values (TLV) are health based guidelines that provide a level of exposure to chemicals that are thought to allow *'nearly all workers'*, to be exposed to such levels without any adverse health effects. [294] They represent airborne concentrations of individual chemical substances and only consider absorption via inhalation and are valid as such only on the basis that significant skin absorption cannot occur. [97] Many in the aviation industry and Governments repeatedly state that the air is safe as all levels recorded are below government set standards using statements such as *'levels of measured air pollutants were always below any recommended health limits'*. [295] Synergistic effects occur when two chemicals have an effect individually and a more than additive effect when together. However exposure standards or TLVs apply to one chemical only and do not cover the synergistic effects of being exposed to several chemicals simultaneously in a reduced pressure environment, as acknowledged in the UK House of Lords in 2005. [296] As the exposure standards apply to *'nearly all workers'*, it cannot be assumed all workers are protected and therefore reliance on exposure standards can be flawed. [297] Quite clearly exposure standards do not apply to non workers and should not be used as the basis for evaluation of community air quality, or for long-term non occupational exposures. [97] The TLVs are based on exposures for (nearly all) normal *'healthy adult workers'* and do not take into account the elderly, young, immune compromised or pregnant individuals. *'Public and occupational limit exposure values differ, owing to the differences in nature of exposure, exposure duration, and the makeup of the exposed population.'* [33] Exposure guidelines (available for several hundred chemicals only) issued for indoor and outdoor air have been established by non-aviation governmental or intergovernmental organizations (e.g. ACGIH, OSHA, US EPA, WHO) and may cover outside air only and not enclosed spaces. [33]

Exposure standards are not fine lines between safe and dangerous exposures and they do not provide a relative index of toxicity or guarantee protection from discomfort or possible ill-health outcomes for all workers. [294,298] The range of individual susceptibility is wide and it is possible that workers will experience discomfort or develop occupational illness from exposure to substances at levels below the exposure standards. [298] Scientists acknowledge the lack of scientific validity underpinning many exposure standards with best practice to keep exposures to as low a level as reasonably practicable. [297] *'It is a good general policy to keep the exposure to any substance as low as is practicable irrespective of whether present information indicates it is hazardous or not'* with some substances determined to pose long-term health risks at a later date. [97]

Exposure standards are referred to by various terms in different countries. The American Conference of Governmental Industrial Hygienists (ACGIH) established Threshold Limit Values for Chemical Substances Committee in 1941. It was set up to recommend airborne concentrations of agents and exposure conditions for use in the practice of industrial hygiene and by other qualified professionals to protect worker health. These voluntary non consensus standards are health based guidelines and are not based on technical or economic feasibility. [294] However in practice the guidelines are used as the basis of standards used globally.

In 1971, the Occupational Safety and Health Administration (OSHA) was set up in America to enforce the OSHA Act which was established to ensure workers had a right to a safe and healthy workplace. The standards adopted to ensure a safe workplace were developed by the ACGIH. However these *'non'* consensus standards adopted are seen by many as, voluntary standards set before 1971, when the newly created agency (OSHA) adopted them uncritically and unchanged. [299] Standards for some substances were set nearly 40 years ago, not by Government agencies but by private industries through organisations established by them or by voluntary agencies in which industry had a major role. [300] Standards from the 1930s on, were seen as key to industry worried about liability suits with most *'only vaguely dependent upon experimentation and epidemiological study'.* [300] More often than not they resulted from bargains struck between industry leaders and public health officials. [301] Industry knew TLVs were a benchmark of what was achievable, although not necessarily what was safe but continued to rely on the standards for which there was often inadequate information and today look arbitrary. [300] The TLVs however are based on *‘industrial experience’* (what was seen as achievable) and fail to be based purely on health considerations as required. [302]

The dangers of vinyl chloride provide a good example of the ACGIH’s failure to act for over 10 years after the increased toxicity hazards were known and demonstrate industry reluctance to act upon and withhold information on the known increased hazards. [300] Out of the almost 3,000 chemicals produced in large quantities, OSHA enforces exposure limits for fewer than 500. In the past 10 years the agency has issued new standards for only two chemicals and not revised old standards despite new science being available. [299] Successive OSHA administrators have simply recognised that establishing new standards is so time and labour intensive, and will be opposed by industry, that it is not worth expending the agency’s limited resources on the effort. [299] The nature of the standard setting process for recommended concentrations of many occupational contaminants has been questioned. [297,303] As an example, the 1986 TLV documentation placed important reliance on 89 substances based on unpublished corporate communications with another 15 substances assigned TLVs solely on unpublished corporate studies and reports, with most data unavailable for review upon request, even from the ACGIH itself. [303] The conflict of interest in standards setting organisations, failure of the standards setting bodies to update standards with new information or changes in technology and failure of enforcement are all key problems. [304] It is has been widely recognised that TLVs for chemical substances are in *‘most cases poorly supported by scientific evidence’* with the consequences being that *‘such misplaced confidence in the TLVs are profound and global.’* [303] Nevertheless TLVs have been more frequently updated, yet OSHA for example adopted few of these, even though some ACGIH TLVs were revised downward to be more protective. [305]

In the United Kingdom, exposure standards are termed Occupational Exposure Limits (OELs) and are set up under the Control of Substances Hazardous to Health Regulations (COSHH). The TLVs should not be adopted as standards without full compliance with regulatory procedures including analysis of other factors necessary to make appropriate risk management decisions. [294] In the Australian case, permission to use the list of TLVs was given by the ACGIH and these were used as the de facto list of exposure standards by the NHMRC up until 1985. Worksafe Australia chose to no longer use the ACGIH's TLVs as the 1983 list of TLVs became more and more out of date. [297] At the time Worksafe Australia (NOHSC) created its own list of exposure standards, however, as in many countries, the ACGIH were used as the primary source in developing the Australian version of the list. While available exposure standards in the Australian case are found on the HSIS Internet database, under the EU system, the standards are obtained by refering to the ESIS database. [96,104]

Most substances used in industry have not been assigned exposure standards. This does not imply that these substances are safe or non-hazardous. In many cases, there is insufficient information on the health effects of these unlisted substances to allow any regulatory agency to assign an exposure standard, even on a tentative basis. Additionally, some substances previously thought to be comparatively safe have subsequently been found to pose serious long-term health risks. [97,306,307]

A fundamental requirement of the UK Control of Substances Hazardous to Health (COSHH) regulations is that the exposure of employees to such hazardous substances should be prevented, or, where this is not reasonably practicable, adequately controlled. [308] A memorandum of understanding between the UK Health and Safety Executive (HSE) and Civil Aviation Authority (CAA) under the Civil Aviation (Working Time) Regulations 2004, transfers responsibilities for aircrew occupational health and safety to the CAA. [107,109,110,111] While the HSW Act 1974 applies to aircraft in flight or on the ground around the UK, [110,114] the CAA does not enforce the Health and Safety at Work Act 1974 (HSW act) or any associated safety legislation such as the COSHH regulations. [111,115,116] Therefore aircrew, except when on the ground outside the aircraft, are removed from having access to HSE expertise, policies and procedures.

Likewise, in the US case, despite the OSHA Act being established in 1970, Section 4(b)(1) gave Federal agencies the right to exercise jurisdiction over their own workers. [117] In July 1975, the FAA asserted their claim of exclusive jurisdiction over the safety and health of crewmembers. [118,309] Consequently the FAA claimed exclusive responsibility over occupational health and safety on board US registered aircraft. As a result, crewmembers were exempted from the protections of the 1970 OSH Act. In the Australian case, while Safework Australia does have jurisdiction over workers when the guidelines are adopted by the various states, Safework Australia have been known in the case of aircraft fumes, to simply defer responsibility to CASA as the issue was too complex. [127]

Exposure standards should not be applied to aviation.

A number of factors show that in practice, exposure standards should not be applied to the aircraft environment. *'The aircraft cockpit and cabin are unique workplaces that cannot be compared with industrial and other workplaces on the ground. Aircrew members are required to perform complex tasks requiring high level cognitive skills, which may be much more sensitive to insult by hazardous contaminants in the smoke/fumes, such as tricresyl phosphate (TCP). Therefore, the maximum permissible limits for safe exposure recommended by OSHA in the USA, and the ACGIH for industrial workers cannot be applied to aviation.'* [310] The specialised working environment of an aircraft cabin cannot and must not be equated with workplaces at seal level or workplaces where specialised ventilation or escape are possible. [227]

The Aerospace Medical Association recognises that *'OSHA standards (and others throughout the world) are not applicable to aircraft cabin air'* and that these terrestrial standards should not be applied to workers or passengers in the aircraft cabin in flight. [311]

A leading aviation industry bleed air specialist has clearly addressed the inappropriate use of exposure standards when stating '*Current safety standards differ from air quality levels that will provide a perceived acceptable level of customer and crew satisfaction. Contaminant levels may be well below recommended levels in currently accepted safety standards yet generate complaints, because they act in synergy with other contaminants or because some standards may be outdated and not have incorporated more recent scientific and medical evidence. In addition, extenuating circumstances on board aircraft (including humidity and cabin pressure) have not been studied to* *the extent that a new standard can be proposed which incorporates these factors or identifies interactions between factors'*. [255] As such there is no agreement among aviation toxicologists on what standards should apply to aviation workers in a reduced pressure environment given there are only standards that apply to those working at or near sea level or astronauts in space. [248] Difficulties in applying TLVs derived from industrial settings to an aviation environment occur with *'transient slight impairment of performance that may be quite acceptable in a factory is unacceptable in a pilot. The exposure may occur in a combination with stressors common in flight: low pressure, high temperature, sustained acceleration. These can modify considerably the intensity and nature of the effects produced by the noxious substance. More than one agent may be present, so that the combined toxicity must be considred… exposures in flight tend to be short but intense… the continual changing gaseous environment in the crew compartments of aircraft in flight tends to produce wide and rapid fluctuations in chemical composition in the air… thus TLVs must be applied with caution in aviation and are no more than a general rule, especially for the relative toxicity of different materials.'* [312]

According to SAE, TLVs *'are addressed for single components… Occupational and public exposure limits apply only to exposures to a single chemical at a time. They do not reflect the actual situation in aircraft cabins, where contaminants may be present in a blend, and the possible effects of altitude on toxicity mechanisms. Also, exposure standards or limit values do not exist for all chemical species, or the various possible isomers.'* [33]

ASHRAE in 2010 draft guidelines suggests that: *'Health-based exposure limits suitable for crewmembers and the flying public have not been defined for either TBPs or TCPs. The presence of hundreds of additional compounds in supply air contaminated with pyrolyzed oil or hydraulic fluid further complicates efforts to define acceptable exposure limits, either for individual compounds or families of compounds.'* [313]

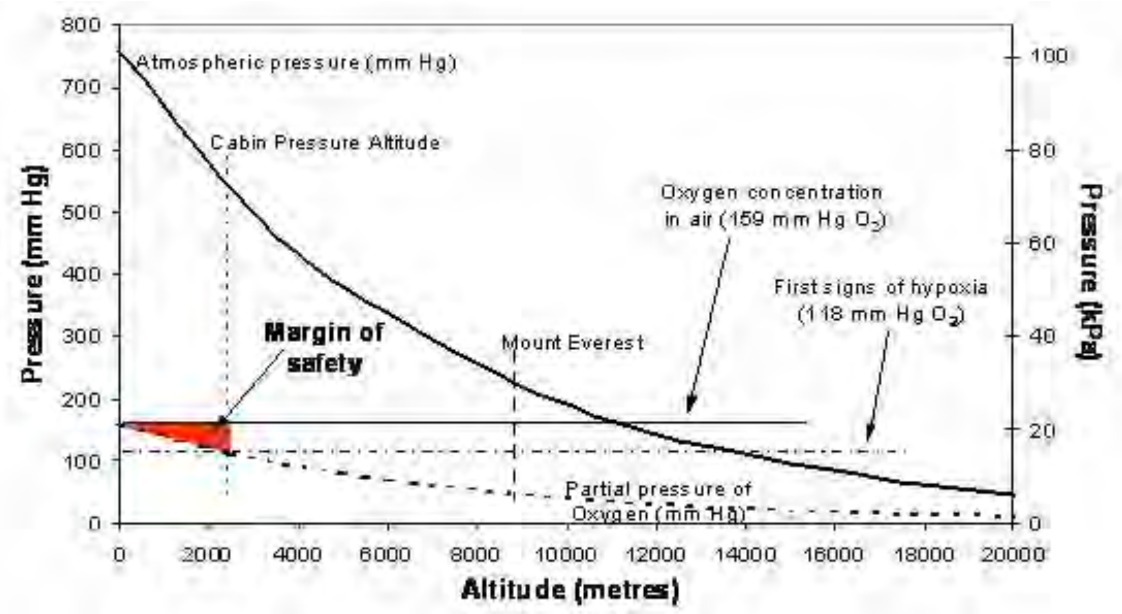
2.5.2 Effects of altitude

A combination of factors must be considered in flight, which can modify the intensity and effects produced by a noxious substance. Concentrations of contaminants in the cabin air that would not be of significance at sea level may become a hazard at altitude, by an interaction with the hypoxia of pressurisation [182] and may reduce pilot performance. [312] Additionally in the air, thermal decomposition by overheating may convert relatively non toxic materials into toxic gases or vapours. [312]

As shown in Figure 2-12 as the atmospheric pressure declines, the proportion or concentration of oxygen remains unchanged (20.9%), however the (absolute amount) partial pressure of oxygen in the air decreases. At sea level the partial pressure of oxygen is 159 mm Hg. At a cabin pressure altitude of 8000 ft (2438 m) the oxygen partial pressure is 118 mm hg so as to prevent the cabin becoming hypoxic during normal operations. [182] The minimum oxygen concentration for work is considered to be 136 mm Hg (18%) oxygen at sea level. [97] The altitude at which partial pressure of 136 mm Hg is reached is close to the pressure at which the cabin is pressurised (118 mg Hg). Therefore there is little margin for safety for people working at altitude, as workers may not obtain enough oxygen for their physiological requirements. [182] The aircraft cabin (the working environment for crew) therefore becomes hypoxic. [227]

Figure 2-12: Pressures and oxygen concentrations at altitude

(from [182])



Assumptions:

- Atmospheric pressure: 101 kPa (760 mm Hg) at sea level

- Proportional concentration of O_2 in air: 20.9% (21 kPa or 159 mm Hg) at sea level
- Aircraft Pressurisation Pressure: Equivalent to an altitude of 2438 m (8000 ft).

The ACGIH recommends a minimal oxygen partial pressure of 132 mm Hg (torr) to protect against inert oxygen displacing gases and oxygen consuming processes up to 5000 feet. [314] A partial pressure of 132 mm Hg is seen as an oxygen deficient atmosphere and at elevations greater than 8000 feet, the partial pressure of oxygen is expected to be less than 120 mm Hg. [314] No adverse physiological effects should occur in healthy adults at partial oxygen pressures above 132 mm Hg and altitudes less than 5000 feet. [314] At less than 120 mm Hg symptoms in *'unacclimatised workers'* include increased pulmonary ventilation and cardiac output, incoordination and impaired attention and thinking which are seen as *'incompatible with safe performance of duties.'* [314] With partial oxygen pressures less than 132 mm Hg additional work practices are required such as a review of the workplace to determine the low O_2 concentration; use of continuous monitors with warning devices; acclimatisation of workers to the altitude and similar. [314] The cabin environment pressurised to approximately 8000 feet is therefore a hypoxic environment to which the same exposure standards cannot be applied as on the ground.

Working in a reduced atmospheric pressure environment with lowered levels of oxygen may result in changes in sensitivity to toxic exposures, as is the case with carbon monoxide with which toxicity is 50% higher at 8000 ft than at sea level. [182] With aircraft pressurised to the equivalent of 8000 ft (2438m), hypoxia may interact adversely with chemical exposures. [315] Therefore the cabin working environment is hypoxic with the possibility of incipient hypoxia leading to higher respiratory rates and therefore higher exposure. [182,227] Except for CO, HCN and several decomposition by-products, which have known increased toxicity at altitude, little information is available on increased toxicity at altitude. [33,316] The effects of hypoxia, pressurisation and low humidity have not been adequately studied but are likely to also have an impact on exposures. [182]

Special care is required to be taken when exposure standards are utilised under adverse climatic conditions, as there may be an increased lung uptake. This is of particular importance when there is a significant airborne concentration of contaminant. [97] Despite the fact that in the UK the COSHH regulations are not in reality applied to aircrew by the HSE or the CAA, the UK has a range of HSE regulations that necessitate substances that may cause harm to health being subject to the 1999 COSHH regulations. These regulations require employers to prevent, or if this is not reasonably practical, adequately control employees' exposure to hazardous substances. There are several points in the HSE guidelines worthy of note. Like the ACGIH, the COSHH exposure standards can only apply in environments where the atmospheric pressure is between 900 and 1100 mb. [317] Aircraft operating at a cabin altitude of 6000 to 8000 feet lie outside this range (8000 ft = 2438.4 m = 752.624 mb/hPa).

2.5.3 Exposure to gases, vapours and particulates

Given that exposure standards apply to airborne concentrations of individual substances for which significant skin exposure cannot occur, it is necessary to review the toxicity of exposure to jet oils. [227] Unlike ground exposure scenarios, airborne exposures lead to a scenario for crew and passengers where they are unaware of what contaminants they are being exposed to, there is little control over exposure and no opportunity of escape. Exposure will be in particulate (mist, fumes, aerosols) form as well as gasses and vapours or a mixed phase. [182] Such particulates can attain higher airborne concentrations than predicted for gasses or vapours and the potential for skin exposure is greatly increased, as the mist can settle onto exposed skin with subsequent availability for skin absorption. Additionally particulates can settle onto the surfaces (ducting, walls, furniture, equipment), which would thereafter vaporise, providing residual exposures. Monitoring programs must clearly be tailored dependant on the type of contaminants applicable in the particular environment.

2.5.4 Combustion and pyrolysis

In addition to the known toxicity of the oils, little is known about the possible chemical transformations that may have occurred in the oil while in operation in the engine. Breakdown processes involving thermal degradation can take place, or in the case where oxygen is completely lacking, pyrolysis would occur. Varying complex pyrolysis products can form as the reaction process proceeds. These will vary depending on the source materials, the temperature and the duration of combustion and the progressive combustion of the pyrolysis products that occur in the thermal degradation process. Contaminants from engine oils or hydraulic fluids entering the air supply system from the engine or APU may have been subject to temperatures exceeding 500°C [318] or higher (up to 650°C in the compressor) As such pyrolysis can be expected resulting in a breakdown of products that could have unexpected effects on the aircraft occupants. Oil leaking from the engine at altitude would see most of the oil pyrolised. [227] Upon heating, the oils and fluids to simulated temperatures in aircraft, carbon monoxide was shown to release into the atmosphere indicating pyrolysis of some of the constituents had taken place. [319] Additionally the cocktail of chemicals that could be formed along with CO could be expected to include CO2, partially burnt hydrocarbons (including irritating and toxic by-products such as acrolein and other aldehydes) and potentially TMPP. The contaminants can be in the gas, vapour, mist and particulate forms and cannot be classified as being of low toxicity. [227] Exposure to such a cocktail cannot be dismissed without due consideration. SAE clearly states that: [33]

- *'Thermal decomposition of lubricating oil, hydraulic fluid, and fuel take place within engines and APUs. If this occurs, the chemical species can differ from the original fluid compounds.'*

2.5.5 Synergism

Substances that are affected by synergism, which cause the most serious health effects and require the most strict control, are the most difficult to assess and therefore must be carefully interpreted with specialist advice. [317] The presence of a complex chemical mix during an exposure event can include substances that can alter the toxicity of a particular exposure as some of the substances may have a synergistic toxic effect with other agents present. Such complex effects cannot be ignored without proper consideration, however they often are. [182,254] *'Combined exposures to two or more compounds may result in synergistic/potentiation effects.'* [33] In addition to the complex cocktail of substances identified in cabin air monitoring to date, [320] examples of chemicals that are known to have synergistic effects are the increased effect of a carbon monoxide exposure at the lowered levels of oxygen at altitude and the synergistic effects of exposure to organophosphates (TCP) and pesticide permethrins. [227,284]

There are several difficulties associated with risk assessments of chemical mixtures. One difficulty in assessing the potential effects of exposure to mixtures of chemicals present at low concentrations is that most experimental data on the effects of exposure to chemical mixtures have been obtained from studies using relatively high levels of exposure. The type of combined action or interaction found at clearly toxic effect levels may not predict what will happen at lower levels. Not all interactions are easy to predict, such as those occurring at the transcriptional level of the genome or second-messenger signalling pathways. Hence, there could be many uncertainties in the hazard assessment and estimated dose-response relationships for chemical mixtures. [321] Such a scenario has recently been suggested with assumed low level TCP exposure on aircraft where the symptomology identified is different to the classic case of widespread high dose exposures. [322]

2.5.6 Concerns with exposure standards

Even though exposure standards should not be applied to the aviation industry, it is important to understand some of the exposure standard application guidelines. These clearly demonstrate how absolute caution would have to be used in applying such guidelines if they had been applicable, yet even this is clearly not occurring within the aviation industry. [97,294]

Exposure standards are only applicable to workers and do not apply to passengers. In fact the entire concept of using TLVs is inadequate in protecting special needs populations outside the workplace. [300] The standards will not *'adequately protect all workers'* with some individuals experiencing discomfort or more serious adverse health effects. [294] The standards must not be used to prove or disprove disease or physical condition and do not represent a fine line between healthy and unhealthy work environment. [294] They represent inhalation exposure only to individual substances and do not apply where significant skin exposure can occur. The ortho isomers of TCP in the oil are known to be a significant source of skin exposure [323] as is the case with Ethylene glycol. Ignoring skin exposure can underestimate overall exposure which can be significant. [297]

Caution must be applied when using the standards for mixtures by way of additive effects as additional hazards may arise. The use of exposure standards assumes the interaction of multiple chemicals can be estimated additively by summing exposures as a fraction of their exposure standards. [324] This however ignores the fact that most chemicals do not have exposure standards. While the ACGIH recommends that *'special consideration'* is used when looking at additive effects of mixtures, exposure standards do not take into account synergistic effects as the present understanding of such effects is incomplete and therefore exposures should be kept as low as practical. [97] The use of standards that cannot take into account synergistic effects is deemed *'fundamentally illogical'*. [297]

The aircraft environment also needs to be looked at in terms of whether it is a deemed a normal workplace or a confined space from which there is restricted means of entry/exit for which additional guidelines apply. [33,325]

Some substances are prohibited from use due to the risk of serious occupational disease. These are usually the more potent probable and established human carcinogens, for which it is not currently possible to assign an appropriate exposure standard. For these substances, exposure should be strictly controlled to the lowest practicable level or replaced where possible so as to prevent worker exposure. Biological monitoring may provide a more reliable indication of workplace exposure for these substances, as is the case where skin absorption occurs. One such substance known to be in the oils, is 2-naphthylamine a known potent human carcinogen. In the UK it appears in Schedule 2 of the 1999 COSHH regulations, which prohibits its *'manufacture and use for all purposes'.*

Many chemicals present during a contaminated air event have not been assigned exposure standards. This does not imply that these substances are safe or non-hazardous. In many cases there is insufficient information on the health effects of these unlisted substances to allow exposure standards to be determined. The -ortho isomers of TCP, MOCP and DOCP present in the engine oils do not have exposure standards but their severe toxicity has been known and discussed for over a hundred years. [238,257,272,326]

The application of exposure standards by a suitably qualified expert must take into account a wide range of variables including: the standards are based upon 8 hour shifts under normal climatic condition with a 16 hour period between shifts to eliminate absorbed contaminants; Situations with an increased cardiopulmonary demand such as or strenuous work under adverse climatic condition (extreme heat/cold/relative humidity) or work at higher altitudes or reduced pressure may increase lung uptake of contaminants and *'extreme care'* should be exercised if workers are exposed to very high or low ambient pressures. In summary, sampling results obtained under unusual climatic conditions cannot easily be compared to published TLVs. [294]

Some individuals will have an increased susceptibility based on age, gender, ethnicity, genetic (predisposition), medications, pre-existing conditions (e.g. aggravation of asthma, cardiovascular disease), previously exposed workers who have become sensitised, workloads, climatic conditions such as extreme heat or cold, variations in fetal development and throughout an individual's reproductive lifetime.

Substances that can lead to sensitisation, manifested as a skin rash, asthmatic condition or other reaction may allow a *'sensitised'* person to subsequently react to exposure to minute levels of that substance. Such people should not be further exposed to these substances. [97] PAN at the levels found in the oil is a listed as a skin sensitiser, as are formaldehyde which has been found in the aircraft air after oil leak events and propylene glycol found in deicing fluids, indicating real caution is required. Compliance with recommended exposure standards may not provide adequate protection for a hypersensitive individual. [97,327,328]

Caution is also required when dealing with substances that may affect the skin or mucous membranes. TBP in the hydraulic fluids is a known skin irritant, while TCP in the oils is an irritant to the skin causing allergic dermatitis and mucous membrane irritation. [329]

Additionally there can be a wide variation of exposure standards between the agencies that set the standards in different countries, indicating different approaches are taken in the standards process. [294] Importantly the NOHSC in Australia and the ACGIH provide strong cautions for the inappropriate use of exposure standards. [294] Use outside the clear guidelines deletes any ACGIH liability. [294] Adjusted TLVs do not have the benefit of historical use and long-time observation and medical supervision may be required at such times. [294] Finally TLVs or exposure standards are only one of multiple factors to be considered by industrial hygienists in evaluating specific workplace situations and conditions. [294]

2.5.7 Case study – tricresyl phosphate (TCP)

Despite the fact exposure standards should not be applied to the aircraft environment, the use of the exposure standard for TCP should be examined. The only exposure standard applicable to TCP, is that listed for TOCP at 0.1 mg/m^3. Even ignoring the aviation setting, the use of the TOCP TLV should not be applied to the other 9 isomers of TCP. In 1958 the other ortho isomers of TCP, MOCP and DOCP were found to be 10 and 5 times more toxic respectively than TOCP. [257] The 1958 research finding stated that: [257]

- *'Previous calculations of the toxic human dose were based on the amount of ortho cresol contained in a preparation and related this amount to TOCP, in belief that the bound proportions of meta-cresol and para-cresol have no effect on the toxicity of the total preparation. However since the meta and para isomers that are present can cause the formation of the mono-ortho and di-ortho esters… The toxicity of the mixed esters is much greater than the TOCP, the old method of calculation, is invalid.'*
- *'It is no longer permissible to relate an analyzed proportion of ortho cresol to tri-ortho-cresyl phosphate' ...The term tri-ortho cresyl phosphate poisoning should no longer be used, instead the more general and more accurate tricresyl phosphate poisoning should be used.'*

The awareness of the increased toxicity of the ortho isomers other than TOCP, particularly the MOCP was recognised by Mobil referring to Henschler's work dating back *'at least 40 years.'* [226,238] This awareness clearly led to the questioning of the adequacy of the TOCP exposure standard being applied to total TCP concentrations in statements including:

- *'Contrary to common belief, many components of TCP other than TOCP can be neurotoxic. For this reason it would be prudent to review the current workplace exposure standard, which applies only to TOCP.'* [272]
- *'One might incorrectly imply that TOCP standards are adequately protective for products containing TOCP. However, TCP consists of a mixture of isomers… This calls into question the adequacy of exposure standards which rely only upon the evaluation of the concentrations of the tri-o-isomer of TCP in the atmosphere. It is possible that the standard promulgated by US OSHA has been based upon the assumption that the tri-o-isomer was primarily or solely responsible for the neurotoxic properties of TCP',* [238] which it is not.

Therefore if 0.1 mg/m^3 is the recommended standard for TOCP, an equivalent standard for MOCP should be one tenth the value of this, or 0.01 mg/m^3. This value would be precautionarily protective for all ortho cresyl phosphates (OCP). However it is also necessary to look at the suitability of the exposure standard itself. Henschler questions not only the lack of relevant data on which exposure standards are based, but in the particular case of TOCP the exposure standard was established on *'a very vague basis of data'*. [330] According to Henschler, who was investigating OCP as an additive in paint lacquers on German railways after the war, the TOCP exposure standard value *'comes from two Englishmen who have been paralysed during World War II, and there have been two or three air analyses performed there. This is trivial data to establish an official occupational standard.'* [330] Instead it is necessary to look at the mixtures as they are very complex, vary in the content of the individual compounds and they are changed in the course of being heated up, so that decomposition products will occur necessitating the need to look at what is in the exposure air. [330] The term TCP has also been (incorrectly) used to cover a variety of triaryl phosphates, [226,228] which also will not be covered by the TOCP exposure standard. Additionally preliminary studies of dermal exposure to rats have shown to not only affect the TOCP isomer, but also the non ortho isomers

(TMCP/TPCP) caused sensorimotor defecits and neuropathological lesions in the brain. [260,261] This is supportive of the concern that it is not only the ortho isomers that are neurotoxic and the inappropriateness to refer to an exposure standard that is suitable for the TOCP isomer only.

The increased toxicity of other TCP (MOCP/DOCP) isomers over TOCP has been recognised in a number of studies (Henschler 1958: Glees and Janzic 1965: Johnson - 1975) however little thought has been given to the neurotoxic potential of the other isomers in the TCP other than TOCP. [241] Therefore it is impossible to erect exposure standards for TCP without qualifications and specifications that define the relative toxicity of the particular brand of TCP, given it is made up of a mixture of isomers, of which TOCP is not the most toxic. [238] While the meta and para isomers of TCP lead to the formation of the mono and di-ortho isomers the formation of the tri-ortho and di-ortho esters *'is suppressed in favour of the mono-ortho esters.'* [257] In summary *'TOCP standards might not be protective if applied to the total TCP concentrations.'* [238] Therefore estimating *'acceptable'* exposures based on TOCP alone will severely underestimate exposure. [182] Additionally TCP will contain low amounts of mixed esters of orthophosphoric acid (xylenols and phenolics) with different cresyl radicals of the mono and di-ortho types. [182,227] All ortho cresyl phosphates should impact on the regulatory process of materials containing TCP. However, none of the ortho isomers are listed on the majority of the MSDSs.

Interestingly the Australian Defence Force stated in 2008 that: [331]

- *'As a general rule it is recommended that the ADF consider total TCP air concentrations <1 µg/m^3 as a desirable target rather than the statutory exposure limits of 100 µg/*m^3*. This recommendation is based on the uncertainty of toxicity data, the absence of economic imperatives (which provide a rationale for establishing a high exposure level in industry) and the potential for cognitive effects on the flight crews. The target levels appear to be readily achievable and are indicative of the satisfactory condition of the compressor oil seals.'*

ASHRAE has suggested that as there are currently no health based standards that cover TCP isomers (and TBP) that would cover crews and passengers in the aircraft environment and given that there are hundreds of additional compounds in supply air contaminated with pyrolised oil or hydraulic fluid, real time monitoring is required. [313] Such real time monitoring should be used to *'reliably'* detect TCP and TBP at 0.01 μg/m^3 or lower as well as differentiating between them. [313] The suggested level of 0.01 μg/m^3 *'should be used both as a trigger point and an exceedance level. This concentration is not intended to be a health limit; rather, it should be considered an indication of system contamination. The goal should be to prevent any pyrolyzed oil and hydraulic fluid from contaminating the aircraft air supply.'* [313] This level is 10,000 times lower than the current TOCP TLV and 1000 times lower than the suggested Australian Defence Force level for TCP.

Unofficial discussions with an ASHRAE Honeywell member suggest that at Honeywell it is considererd that oil can be smelt at 300 ppb which equates to 9 ppb (0.009 ppm = 0.14 mg/m^3 = 140 μg/m^3) given TCP is in the oil at 3%. which is 14,000 times above the suggested ASHRAE trigger level. [332] The 2002 Honeywell view suggested that the TOCP exposure standard should be 1/10th of the TLV which would provide protection for the crew and travelling public assuming (1/10th safety factor protects sensitive people) exposures were infrequent. [333] Additionally no more than 3 excursions up to 3/10th of the TLV with the maximum allowable excursion time being 20 minutes. [333] However the more recent ASHRAE position has appears to differ from this view.

2.5.8 Industry position

Many airlines and airline industry bodies around the world have stated that their aircraft meet all the regulatory and OHS standards and that the level of contaminants found in the aircraft cabin environment are well below health authority/Government set standards. [34,35,70,123,126,295,334, 335,336,337,338,339,340] Honeywell, a major manufacturer that recognises exposure standards are not applicable still states that *'the quality of the supply air… is within safety limits.'* [255] Airlines have also stated that there is no evidence to suggest that crew or passengers are exposed to levels of contaminants that could be harmful to health. [341] British Aerospace advised the Australian Senate Inquiry that: [123]

- *'We provide quality of air to standards which far exceed the requirements… What we are proud of is the fact that the contaminants that they found in the system are incredibly low, way below the maximum levels that are permitted by the authorities. They compare very favourably with Worksafe and occupational health and safety levels. …they are finding the air quality to be impressive …we can confirm that the BAe146 does comply with all applicable Australian airworthiness standards relevant to the cabin air issue… none of the testing carried out to date has produced any evidence of any such contaminant exceeding or even approaching the currently recognised safety levels.'*

Such statements are frequently made by all sectors of the aviation industry and Government transport departments. The statements are accepted uncritically by those without the necessary skills or independence to interpret the use of monitoring data or lack of it. Internationally accepted bodies continue to apply exposure standards inappropriately to the aviation environment such as the current UK Department of Transport sponsored air monitoring studies. [342] The fact that many chemicals have been identified during contaminated air events, the interaction of such mixtures is completely overlooked. [320]

Synthetic jet engine oils have no published exposure limit, however, a 5 mg/m^3 exposure standard has been published for mineral oils. [95] This must not be applied to (synthetic) oils containing additives or contaminants as used in jet engined aircraft. Despite this, an oil manufacturer states that the risk assessments showed that a potentially harmful dose is not possible via inhalation at levels at or even higher than (mineral oil) TLV of $5mg/m^3$. [183,238] The inappropriate acceptance of the mineral oil exposure standard for ester based synthetic lubricants can be clearly seen in the following statement.

- *'The limit of mineral oil present as a mist in the workplace is 5 mg/m^3 for health and safety reasons (UK HSE). This can produce a visible haze in the atmosphere. For convenience, this level has been adopted for the polyol ester based oils as a limit for calculating exposure to lubricant based contaminants, because no safety limits for ester based oils has been set.'* [343]

As far back as at least 1966 an oil manufacturer, Esso recognized that the mineral oil exposure standard did not apply to synthetic oils for which no limit had been set by the ACGIH. [344] Therefore Esso (inappropriately) suggested the mineral oil limit of 5 mg/m^3 should be used instead.

2.5.9 Challenges to conventional toxicology

The core assumption of regulatory toxicology is that lower doses yield lesser effects, and a higher dose will yield a greater effect. This is known as *'dose response',* derived from 16th century dogma but is still typically applied today by regulators. [345,346] The dose response curve assumes that at a sufficiently low dose, the no observable effects level: NOAEL, becomes zero. The current paradigm in regulatory toxicology of only testing a few very high doses of chemicals within a relatively narrow dose range (with the highest dose being the maximum tolerated dose) does not serve to predict the hazards posed by low-level exposure to chemicals. [345]

Environmental toxins are generally encountered in complex mixtures but most will have been tested individually, however the combined effect might be expected to be additive, antagonistic or synergistic. [347] Synergistic effects arise when the overall toxic effects of a mixture are greater than the sum of the individual components [321] and can be very large with increases in toxicity of more than 100 or thousand fold. [347] This has been observed with acetyl cholinesterase inhibitors and insect repellent (DEET) used in the first Gulf war, in pesticide and herbicide formulations.

A number of fundamental changes between the older or conventional toxicology and new thinking are now available: [347] *'the dose makes the poison'* or the classical dose response curve is now challenged by differing dose response curves in which low level exposure can cause effects that can disappear at higher levels; the assumption that only high levels matter are now challenged by impacts caused by what was previously assumed to be background levels; high level contamination overwhelms detoxification and other defence mechanisms is now challenged by low level contamination takes control of development; the focus on adults is now challenged by periods of rapid growth and development (prenatal through puberty) are most sensitive to exposure; a small number of *'bad actors'* is now challenged by many chemicals previously thought safe are biologically active and capable of interfering with signalling systems; immediate cause and effect is now challenged by long latencies and fetal programming can lead to disease and disabilities decades later; chemicals examined as one compound at a time are now challenged by the fact that in real life mixtures are the rule which can lead to effects at much lower levels than indicated by simple experiments with single chemicals; the focus on traditional toxicology endpoints like mutagenesis, carcinogenesis and cell death are now challenged by a wide range of health endpoints including immune system dysfunction (both hyper and hypo-active); neurological, cognitive and behavioural effects; reproductive dysfunctions; chronic diseases; one to one mapping of contaminant to disease or disability is now challenged by the same contaminant which can cause many different effects, depending upon when exposure occurs during development and what signals it disrupts. Multiple contaminants can cause same endpoint, if they disrupt the same developmental process.

The changing views on toxicology can be seen in an increasing number of studies not limited to: chronic or subchronic exposure to small daily doses are more toxic and efficient in producing OPIDN than large singles doses; [260,348] organophosphates have greater access to neurotoxicity targets through inhalation, and dermal exposure than oral exposure, with inhalation being the most effective; [260] concurrent exposure to organophosphates and other chemicals increased the neurotoxic action of the individual chemicals; [349,350] PON1 status modulates the interactive toxicity of OP compounds - (particular relevance for newborns and young children, who have very low levels of PON1); [351] Long-term subclinical exposure to organophosphates without previous acute poisoning have been documented in humans and animals related to chronic neurotoxicity. [260] Tokyo subway passengers exposed to sarin and rescue workers who failed to develop acute neurotoxicity, reported chronic effects several years later, [352] while Gulf War veterans reported chronic symptoms after low level exposure to sarin released into the atmosphere, [353,354] with follow up studies in rats exposed to sarin showing small doses resulted in delayed apoptotic neuronal cell death, [260] while larger doses led to acute necrotic death of brain neurones; [355] a single 0.5 x LD50 dose of sarin which did not induce seizures, caused delayed apoptotic death of rat brain neurones 24 hours after dosing, while those treated with a single 0.1 x LD50 dose of sarin which did not exhibit brain histopathological alterations 1, 7 or 30 days after dosing, showed apoptotic death of brain neurons in the same regions one year after dosing. [260,261] More recent dermal exposure studies investigating non ortho TCP isomer toxicity are reporting chronic neurotoxic effects. This is a step away from traditional toxicological studies, which referenced TOCP and OPIDN only. [260]

A highly relevant example that demonstrates the fact that it is not the individual compounds referenced to the classical dose response curve, but rather the complex mixture that is relevant, occurred one night over Sweden. In November, 2001 the Swedish Statens Haverikommission (SHK) Board of Accident Investigation issued a report known as 'Report RL 2001:41e', [139] which centred on an incident of contaminated air onboard a BAe 146-200 series aircraft registered SE-DRE during an internal flight between Stockholm and Malmö, on 12 November 1999. Adverse effects were noticed on the previous 2 flights by the 3 cabin crew members; however the cause was not apparent and no fumes were detected.

During the incident which occurred on the third flight of the day, the two pilots were temporarily incapacitated in the descent at night. One the four engines on the aircraft was found to be leaking oil (dripping with oil according to the captain) along with a number of minor defects and was removed from the wing of the aircraft and sent back to the manufacturers, Honeywell, for analysis.

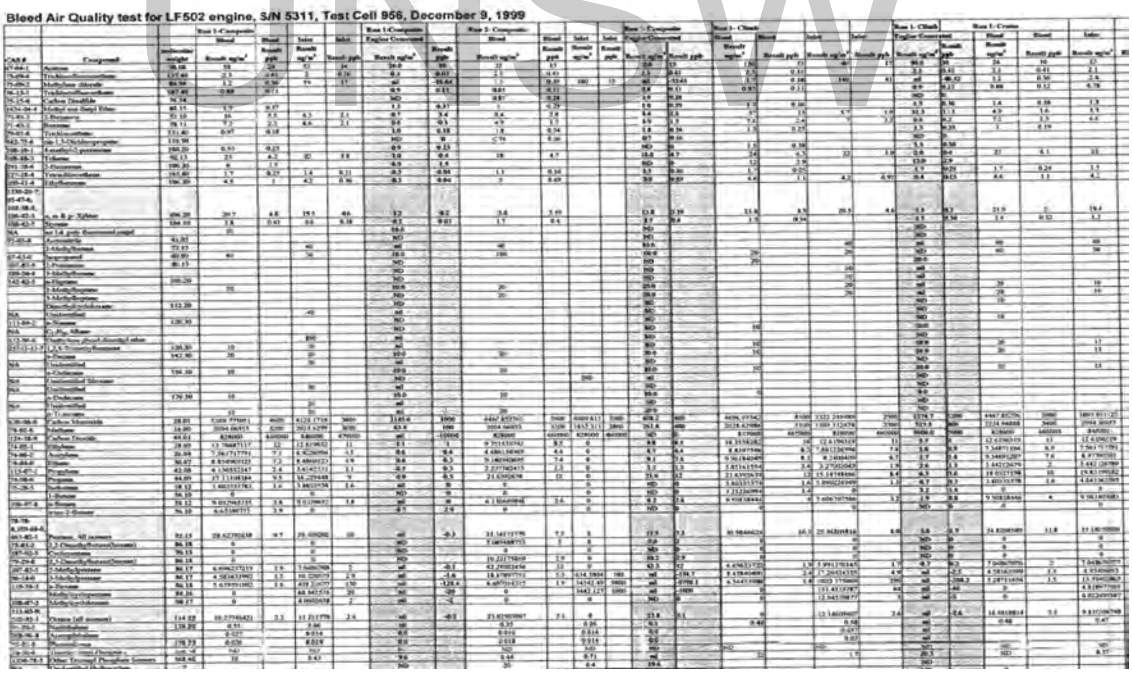
After extensive testing and analysis, a detailed spreadsheet of in excess of 100 chemicals released into the bleed air (Figure 2-13), from the defective engine, was released and included the following reported values: [249,250]

- TOCP - Not detected
- Other TCP isomers (CAS 1330-78-5) (various locations) - max 22 µg/m^3
- Hydrocarbon matrix - max 500 µg/m3 ('broad mix of very heavy tar like co-eluting compounds') [251]
- Total unidentified hydrocarbons - max 80 µg/m^3

- Formaldehyde - max 45 µg/m^3
- Triphenyl Phosphate - max 8 µg/m^3
- PPM Contaminants as oil - max 41.6 ppm

The report found that *'the incident was caused by the pilots becoming temporarily affected by probably polluted cabin air'*. [139] In fact all the chemicals detected and reported to be present by Honeywell were stated as being well below established CAA/FAA limits, even though it was stated that no FAA or JAA limits existed for the compounds detected. [249] However, the synergistic effects of inhaling the mixture of chemicals released into the bleed air from the engine incapacitated both the Captain and the co-pilot for at least five minutes. [356] The captain who is no longer able to hold a medical certificate to fly stated that after landing the passengers were mostly asleep and hard to wake up, [356] while the cabin crew all experienced severe adverse effects in flight. [139]

Figure 2-13: Chemicals present in Swedish SHK BAe 146 investigation


Bleed Air Quality test for LF502 engine, S/N 5311, Test Cell 956, December 9, 1999

In 2006 a Swiss Air Accident Investigation Bureau report on a serious contaminated air incident attributed the incident to the fact that the cockpit filled with fumes which caused a toxic effect, leading to the copilot feeling unwell and in a *'bad condition'* including respiratory symptoms and causing awareness but limited ability to carry out his duties. The report acknowledged the fumes were caused by an oil leak, the aircraft had a history of this and that the medical examination of the copilot after the flight showed that during the flight, toxic exposure took place. While the oil leak was detected, the investigators did not feel there was a need to establish levels of contaminants the crew would have experienced, as the leak was confirmed, there was a history of fumes and this was acceptable to the Swiss investigation. The report indicates evidence that the synergistic effects of being exposed to a complex cocktail of chemicals, released from heated engine oil, is a serious flight safety and health concern. [357]

2.5.10 Standards

While the FAA has set standards only for CO, CO_2 and O_3, ventilation and cabin pressure, all other contaminants while in fact covered under the Federal Aviation Regulation (FAR) have not been specified. Federal agencies such as US OSHA and Environmental Protection Agency (EPA) have not set standards necessarily appropriate for the unique environment of an aircraft cabin and the existing ground based standards are also inappropriate. [304] In the US the EPA sets standards (limited chemicals only) for the general public including sectors of the population that may be the most vulnerable. Since airlines serve the same general public, and include passengers that are in the vulnerable groups, EPA's ambient air quality standards could serve as a starting point for aircraft cabin air standards, however there are other standards that could also be considered. [304] Ambient standards for the general public are often 100-1000 times lower than occupational exposure standards. [227]

Given that most chemicals do not in fact have exposure standards, it is therefore difficult to suggest they should be revised downwards. There needs to be a fundamental rethink on what levels are satisfactory in the aircraft cabin where both workers and the public are placed in a situation from which they cannot escape and there is limited control. Given ambient standards (where they exist) for the public can be orders of magnitude lower than occupational, a major rethink is required. Standards applied need to be true health standards, rather than comfort standards or industry selected standards. The fact that most chemicals do not have standards must also be addressed. The need to reduce levels even further to take into account a pyrolised mixture of heated chemicals at a low relative humidity, low pressure cabin altitude and the synergistic effects is additionally required. There is a fundamental need to define requisite control measures to prevent exposure to chemicals rather than purely relying on standards for individual chemicals on the ground when in fact exposure is taking place to a heated mixture.

Setting standards has been a political as well as a scientific action, which must now be freed of corporate influence with the decision process including real representatives of exposed people. [303] The future setting of standards for this unique environment must be undertaken by independent non aviation industry expertise.

SAE, an aviation industry body, summed it up well when stating: TLVs address single contaminants; they do not reflect the actual situation in an aircraft cabin, where contaminants may be present in a blend with possible effects of altitude on toxicity mechanisms; many chemicals or isomers have not been assigned TLVs; toxicity will vary according to dose and mechanisms of exposure and individual susceptibility factors; Concentration of contaminants, duration of exposure and frequency of multiple exposures are factors influencing the symptoms; Combined exposures to two or more compounds may result in synergistic/potentiation effects. [33] However despite this the Aerospace medical Association has endorsed the summation principle and the FAA and UK CAA have certified engine bleed air based on ACGIH TLVs and similar. [33]

2.5.11 To Summarise

Heated or pyrolised engine oil inhalation studies have never been published and therefore the extent of their predicted adverse impact on those being exposed; both short and long term is not properly understood. Quite clearly the industry practice of relying upon safe levels or exposure standards is not appropriate and recognised by many within and outside the aviation industry for a variety of reasons. Accepted levels where they exist are often based on high individual levels of exposure rather than mixtures of contaminants at lower levels, which may be entirely different. Most chemicals do not have an exposure standard, which does not indicate that they are safe, standards are often outdated, do not apply to complex mixtures and should not be applied at cabin altitudes that modern transport aircraft fly at as they do not comply with the minimum oxygen content required for workers. This specialised work and transportation environment for crew and passengers cannot be assumed to meet the same standards as a ground based environment.

People outside the workforce who enter the aviation environment are not protected by exposure standards which should be reviewed with special consideration given to the unborn and elderly. There needs to be a clear change to emphasize prevention and control as the priority, with new standards developed that have inbuilt correction and protection factors suitable for the aircraft environment that covers both aircrew and passengers including the developing foetus. Any standard used must endorse real time monitoring to ensure compliance based on this specialized environment.

2.6 The Toxicology Debate

2.6.1 Introduction

Exposures to contaminated air include not just one compound but a complex cocktail of hundreds of different chemicals simultaneously in a reduced pressure environment. Exposing the oils or hydraulic fluids to high temperatures and pressures results in the generation of additional chemicals and therefore any reference to the parent cold oil cannot be made. A range of contaminants that can be present in aircraft cabins specifically realted to oils and hydraulic fluids are acknowledged to include: esters used in oils and hydraulic fluids; amines used in oils and anticorrosion coatings; carboxylic acids used in oils, OPs used in oils, hydraulic fluids and pesticides; CO as by-product of incomplete combustion or thermal degradation (fuel, oil, fluids) amongst others. [358]

While there is very limited acknowldgement in the aviation industry that thermal decomposition of lubricating oil and hydraulic fluids can generate chemicals that differ from the original fluid compounds, [33] toxicity concerns related to TCP dates back many years. In 1961 the active metabolite responsible for the toxicity of TOCP was identified, [359,360] while in 1985 the formation of TMPP from thermal decomposition of synthetic oils containing TCP and trimethylolpropane (TMP) esters of carboxyilic esters was identified. [361]

The industry position, when challenged on the toxicology of inhalation of contaminated air, is that the levels of chemicals to which crew and passengers have been exposed to are 1) safe, 2) below exposure standards and 3) that the oil or hydraulic fluids themselves are not harmful. [183,226,238,241,272,273, 278,334,362,363,364,365,366,367]

2.6.2 The exposure

To understand the toxicological impacts of exposure to contaminated air, it is necessary to know the chemical composition of the exposure and the concentrations of the chemical components of the exposure. There are numerous variables that define and differentiate one exposure and its potential impact from those exposed from another exposure. When exposed to contaminated air the variables of that exposure will include but are not limited to the following in the case of oil contamination:

- Base stock of the original synthetic jet engine oil;
- Type and concentration of the antiwear additive used in the oil formulation e.g. tricresyl phosphate or triphenyl phosphate, at 3 or 5%;
- Type and concentration of the antioxidant used in the oil and the impurities present during the manufacture of the antioxidant used e.g. N-Phenyl-alpha-naphthylamine;
- Temperature and pressure to which the oil has been exposed;
- Decomposition by-products;
- Amount of oxygen present when the oil was exposed to heat;
- Type of engine used and the metals within that engine with which the oil comes into contact;
- Length of exposure;
- Altitude or cabin altitude at time of exposure;
- Concentrations of the chemical components of the exposure;
- The age, gender and general health of the person being exposed;
- The genetic makeup of the individual exposed;
- The exposed individuals previous exposure history to not only contaminated air but any other chemical exposure prior to the current exposure;
- Medications or other supplements an individual may be taking at the time of exposure that influence the levels of liver enzymes that convert tricresyl phosphate (TCP) to highly toxic metabolites.

It is evident how varied exposures can be. Unlike a normal work force in a factory where exposure may be limited to a single toxic chemical within a clearly defined work shift period, contaminated air exposures in aviation have a nearly endless number of variables and permutations to be considered when considering the toxicological impacts of such exposures.

It is for these reasons that the UK Government, when asked in October 2005 *'What exposure standards currently apply to any synergistic effects of simultaneous exposure to numerous chemicals which may be experienced by aircraft passengers and crew during a contaminated air event in a reduced pressure environment'* responded *'None.'* [296] Additionally in 2009 the German Government was asked if exposure to contaminated air on aircraft was harmless and replied *'No'*. [368]

For the reasons outlined above, meaningful exposure standards cannot be formulated. In 2004, the Royal Australian Air Force (RAAF) raised serious concerns about industry misusing exposure standards '*as the aircraft cockpit and cabin are unique workplaces that cannot be compared with industrial and other workplaces on the ground. Aircrew members are required to perform complex tasks requiring high level cognitive skills, which maybe much more sensitive to insult by hazardous contaminants in the smoke/fumes, such as TCP.'* [310]

2.6.3 Organophosphates and TCP

Exposure to contaminated air will most likely include an organophosphate exposure. An organophosphate (OP) is the general name for esters of phosphoric acid. Phosphate esters are probably the most pervasive organophosphorus compounds in jet engine lubricants and hydraulic fluids. The OP tricresyl phosphate (TCP) has been found in air testing and swab sampling in commercial jet aircraft (refer elsewhere in thesis) as well as in crew blood tests following an exposure to contaminated air. TCP is tri ester of cresol and phosphoric acid and is used as an anti wear additive in many synthetic jet engine oils. TCP is a known neurotoxin and has been responsible for many deaths and paralyses linked to the high toxicity of the ortho isomers of TCP (TOCP, DOCP and MOCP), even if diagnoses were done 50 years after exposure. [369,370,371]

The terms *'organophosphates* or *organophosphorus compounds'* include a group of insecticides and nerve agents all of which target the enzyme acetylcholinesterase. The term is used often to describe virtually any organic phosphorus compound, especially neurotoxic compounds. OP compounds have been developed for use in industry, medicine and in agriculture, as pesticides, and in warfare as nerve agents. OP pesticides (as well as sarin and VX nerve agent) irreversibly inactivate acetylcholinesterase, which is essential to nerve function in insects, humans, and many other animals.

The understanding of the toxicity of TCP can be traced back to at least the 1920s when TCP was used as an adulterant for Jamaican ginger. This led to paralysis and other irreversible neurological problems in what became known as the *'Ginger Jake'* syndrome in the USA. [372,373,374,375]

Since then, numerous investigations into the toxicity of TCP and its isomers have been undertaken. In 1930 Smith et al confirmed it was the ortho isomers of TCP that were responsible for the paralysis in *'Ginger Jake'* and in 1931 Smith and Lillie produced delayed paralysis in various animals, including chickens to describe the functional and morphological features of TOCP neuropathy. [376,377,378] They showed that after a delay period of 2-3 weeks following exposure to single or multiple doses of TOCP, paralysis of the hind legs in various animals occurred. Neuro-pathologically, degeneration was confined to the spinal cord and peripheral nerve fibres and this delayed neuropathy associated with TOCP (and other organophosphorous compounds) became known as Organophosphate-induced delayed neuropathy (OPIDN). The first recorded cases of OPIDN occurred during the late 19th century from the treatment of tuberculosis patients with products containing TOCP. [379]

In 1954, Aldridge recognised that TOCP itself was a poor inhibitor of cholinesterases, but became a much more potent inhibitor after incubation with rat liver. [380,381] Some of the most extensively studied enzymes in the world are the cytochromes P450s. This is because the livers' role in the elimination of drugs and other chemicals from the body and the role of the P450s in chemical toxicity and in the aetiology of diseases such as cancer is key to providing an understanding of toxicology.

Casida and colleagues in 1961 determined that the active metabolite responsible for the toxicity of TOCP was saligenin cyclic-o-tolyl phosphate (CBDP) a very potent inhibitor of esterases and lipases. [359,360] Nearly 50 years later, the specific P450(s) within the liver responsible for this bioactivation have yet to be characterised.

In 1959, the German scientist Henschler made the very significant discovery that TOCP was in fact the least toxic of the ortho isomers of TCP with DOCP and MOCP being 5 and 10 times more toxic respectively. [257] The neurotoxicity was not based on the TOCP content alone as had been long assumed, but was in fact based on the content of the mixed ortho-cresol esters with those containing the one o-cresol group showing the greatest toxicity. Additionally the other triaryl phosphates consisting partially or completely of phenol and or xylenols have a paralysing action if they contain some o-cresyl. [382,383]

In 1964 Cavanagh showed that the peripheral and central nerve lesions seen following TCP exposure were the result of axonal degeneration and did not reflect primary demyelination. Cavanagh showed that the affected nerve axons degenerate in a *'dying-back'* fashion towards the cell body, i.e. axonal degeneration begins at the most distal portion of the axon and proceeds towards the cell body. [384]

In 1965 Bleiberg and Johnson noted that when TOCP is metabolised to CBDP in the liver, CBDP is at least five times more neurotoxic than TOCP itself. [385] This was an important finding supporting the previous bioactivation findings along with the variation in exposure routes impacting on level of effect. Organophosphate and other chemical compounds have more access to the nervous system and neurotoxicity target through inhalation and skin penetration than the gastrointestinal tract and inhalation is the most effective route of entry, preceded only by intravenous injection. [386] Despite this Mobil stated in 1999 that *'For the purpose of evaluating risks the simplifying assumption that inahaled and ingested doses of aryl phosphate ester are of equivalent toxicity was employed*'. [238] ExxonMobil has undertaken oral toxicity testing of it's engine oils containg TCP as it considered this route of exposure maximised systemic exposure and therefore inhalation and dermal exposure were assumed safer than oral ingestion. [276,278]

Further work by Prineas (1969), Bischoff (1967 and 1970), Spoerri and Glees (1979 and 1980), Veronesi (1984) Stumpf et al. (1989) and Abou-Donia (late 1990s) further investigated OPIDN and further increased the scientific understanding of TOCP exposures.

In the early 1970s Johnson found that approximately 6% of brain esterase activity was not affected by non-neuropathic compounds but was specifically inhibited, irreversibly, by neuropathic chemicals, such as TOCP. (As now known, the TOCP has to be converted to CBDP to exert its neuropathic effects.) Johnson used the term *'neurotoxic esterase'* (NTE) but today this is now referred to as *'neuropathy target esterase'*. Johnson proposed that NTE is the primary target of the organophosphorus esters causing OPIDN. Experimentally, the potency of a specific OP nerve agent to induce OPIDN is correlated to its inhibitory potency for NTE. Neuropathy target esterase is a membrane-bound enzyme. It is widely distributed within the nervous system and in other tissues, but generally it is assayed in brain and spinal cord tissue. Numerous studies show that the ability of an OP compound to cause greater than 70% inhibition of NTE in 1–2 days following exposure is highly predictive of the development of clinical OPIDN 2 weeks later. [387,388,389,390]

Over time it has become very apparent that certain animal species (e.g. cats, dogs, cows, and chickens) were found to be more susceptible to OPIDN-related paralysis, whereas others (e.g. rats and mice) are less susceptible to the ataxia but very susceptible to the pathological changes. Species susceptibility to delayed neurotoxicity induced by TOCP shows an inverse correlation with the rate of metabolic conversion of the TCP ortho isomers to the neurotoxic metabolite CBDP.

As a consequence of a century of research the general thinking at the end of the last century was that there were four distinct outcomes from exposure to OP nerve agents in both humans and animals. These were reported as: [391]

(i) Acute cholinergic effects that occur minutes or hours following exposure, which may lead to mortality or recovery within days or weeks;

(ii) A delayed peripheral polyneuropathy caused by a few OP nerve agents usually occurring weeks following an acute exposure, variously called OPIDN, and from which recovery may be poor;

(iii) Subtle long-term neurological (primarily neuropsychological) effects that sometimes follow recovery from severe acute cholinergic effects, which may last months or even years;

(iv) A delayed intermediate syndrome affecting muscles, expressed as weakness, which can occur days following recovery from severe acute effects and is reversible over days or weeks.

It should be noted, however, that various epidemiological studies have long demonstrated that individuals exposed to a single large toxic dose, or to small subclinical doses, of OP compounds have developed a chronic neurotoxicity that persists for years after exposure and is distinct from both cholinergic and OPIDN effects. [392] This disorder has been referred to in the literature in a variety of ways including: *'Central nervous system effects of chronic exposure to organophosphate insecticides'* (Dille et al, 1964), *'chronic neurobehavioral effects'* (Yokoyama et al, 1998), *'Chronic organophosphate induced neuropsychiatric disorder'* (COPIND) (Jamal,1997), *'Psychological and neurological alterations'* (Metcalf et al,1969), *'Chronic central nervous effects of acute organophosphate pesticide intoxication'* (Rosenstock et al,1991), *'Chronic neurological sequelae'* (Steenland et al,1994) and *'Delayed neurologic behavioural effects of subtoxic doses'* (Scremin et al, 2003).

In 2005 Professor Abou-Donia reviewed the literature and stated that *'these studies describe a nervous system disorder induced by organophosphorus compounds which involves neuronal degeneration and subsequent neurological, neurobehavioural, and neuropsychological consequences'* that he terms OPICN, *'organophosphorus ester-induced chronic neurotoxicity.'* [260,393]

OPICN is characterised by long term, persistent, chronic neurotoxicity symptoms in individuals resulting from acute exposure to high doses that cause acute cholinergic toxicity, or from long term, low level, sub-clinical doses of these chemicals. Although the mechanisms of this neurodegenerative disorder are yet to be defined, available data suggest that large toxic doses of OP compounds cause acute necrotic neuronal cell death in the brain whereas sub-lethal or sub-clinical doses produce apoptotic neuronal cell death and involve oxidative stress. [260,393] Abou-Donia stated: [392]

- *'Furthermore, OPICN induced by low-level inhalation of organophosphates present in jet engine lubricating oils and the hydraulic fluids of aircraft could explain the long-term neurologic deficits* *consistently reported by crewmembers and passengers, although organophosphate levels may have been too low to produce OPIDN.'*

The concept of OPICN encompasses structural, functional, physiological, neurological and neurobehavioural abnormalities, including neuropsychiatric alterations. OPICN is reported as having the following characteristics: [260, 392,393]

- It is produced by exposure to large acutely toxic or small sub-clinical doses of organophosphorus compounds;
- Clinical signs consist of neurological and neurobehavioral abnormalities;
- Persistent, long-term clinical signs continue for a prolonged time, ranging from weeks to years after exposure.;
- Nervous system damage is present in the peripheral (PNS) and central nervous systems (CNS), with more involvement of the latter;
- In the brain, neuropathological lesions are seen in various regions including the cortex, hippocampal formation, and cerebellum;
- The lesion is characterised by neuronal cell death resulting from early necrosis or delayed apoptosis;
- Neurological and neurobehavioral alterations are exacerbated by combining exposure with stress or other chemicals that cause neuronal cell death or oxidative stress.
- Because CNS injury predominates, improvement is slow and complete recovery is unlikely.

Today, all OP pesticides sold in the USA are screened routinely for OPIDN toxicity with a standardised Environmental Protection Agency (EPA) hen assay. The hen is the accepted animal model and develops clinical signs similar to those seen in humans. [394]

As a consequence of the focus on OPIDN oil manufacturer's state it is possible to cover the *'entire body surface with an oil containing 3% TCP for 6 hours'* without the oil being toxic or causing an adverse neurological effect. [272,395] However industry testing to date has been carried out by administering cold engine oil or its ingredients orally or dermally to hens and has focused primarily on OPIDN as the end point of exposure, ignoring all other medical effects completely. [183,214,226,238,272,276, 277,278] Additionally most studies have focused on TOCP and (wrongly) accepted this as an acceptable surrogate for all ortho isomers even though these are more toxic than TOCP. [238]

US Naval studies of triaryl phosphates found it *'highly suggestive that components other than just the ortho tolyl groups have significant paralytic activity or capable of synergising or potentiating the toxic effects of tri aryl phospha*tes'. [259]

Additionally preliminary studies of dermal exposure to rats have shown toxicity to not only the TOCP isomer but also the non ortho isomers (TMCP/TPCP) resulting in sensorimotor deficits and neuropathological lesions in the brain. [260,261] This is supportive of the concern that it is not only the ortho isomers that are neurotoxic. It also questions the inappropriateness of referring to an exposure standard that is suitable for the TOCP isomer only, which has been also recognized by Mobil. [238,272]

Manifestations of OP poisoning can occur within the optic system, brain, respiratory system, gastrointestinal tract, urinary tract and genitals, musculature and in the cardiovascular system. Symptoms of cholinergic toxicity from OP poisoning affecting the central or the peripheral nervous systems are shown in Figure 2-14.

The severity of symptoms ranges from mild to severe and repeat small exposures have cumulative effects with early symproms of chronic OP poisoning involving flu-like symptoms, developing to a wide range of clinical manifestations as exposures continue. [260]

Figure 2-14 also shows how diverse symptoms can be even from individual to individual following an OP exposure and hence why it is not easy for untrained medical practitioners to realise an individual has been exposed to OPs. Diagnosis becomes even more difficult when the individual has not been informed themselves, something which continues to occur daily in the aviation industry following a contaminated air exposure. Aircrew are not encouraged to inform passengers of contaminated air exposures.

Figure 2-14: Manifestations of OP poisoning

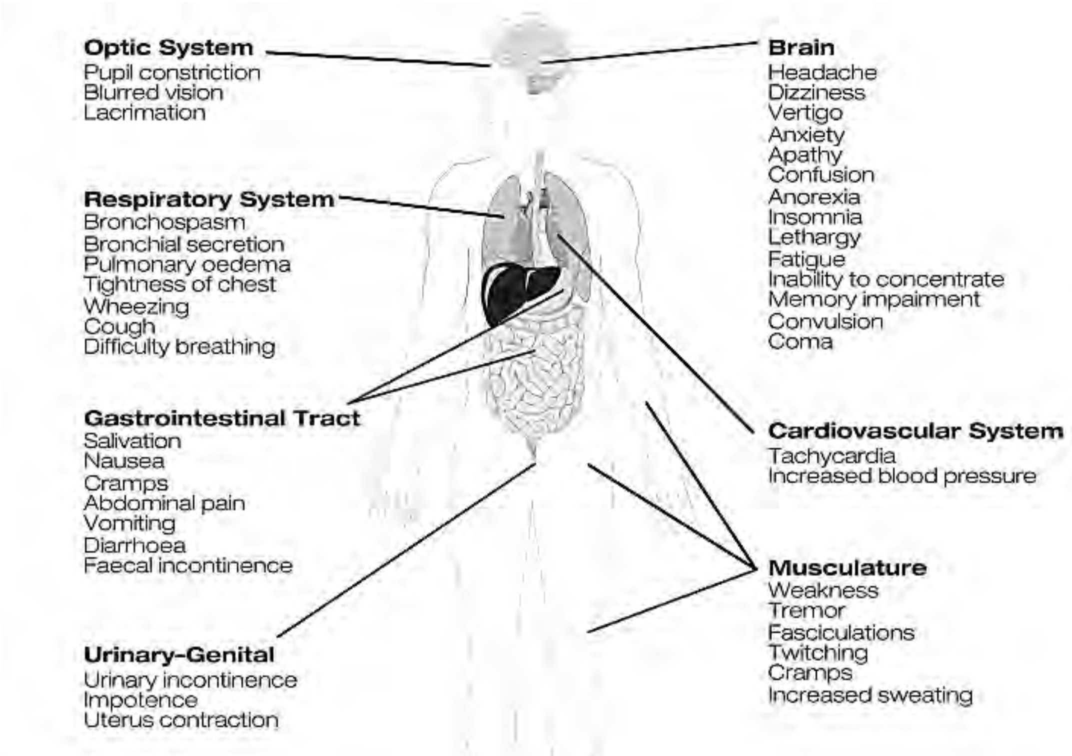


Image courtesy of The Journal of Occupational Health and Safety, Australia/New Zealand, CCH Australia Ltd.

OPICN symptoms which are primarily related to damage to the CNS include: headache, drowsiness, dizziness, anxiety, apathy, mental confusion, restlessness, labile emotion, anorexia, insomnia, lethargy, fatigue, inability to concentrate, memory deficits, depression, irritability, confusion, generalised weakness, and tremors. Respiratory, circulatory and/or skin problems may also be present in cases of chronic toxicity, however again not all people exhibit all symptoms.

Reports of OPICN in individuals following longterm, subclinical exposures, without previous acute poisoning, have been documented in humans and animals. [260] Effects after low level exposure to OPs are reported by pesticide workers, sheep dippers, individuals exposed to low level sarin in addition to those exposed to hydraulic fluids and jet engine oils. [260] While most studies related to synthetic jet oil exposure have focused on exposure to the ortho isomers of TCP and OPIDN, other constituents of the oils should also be investigated. Preliminary results have shown that dermal exposure to each of the three isomers (that is, TOCP, TMCP, and TPCP) caused sensorimotor deficits in rats and neuropathological lesions in the brain. [260] Exposure to tributyl phosphate; tri-isobutyl phosphate; butyl diphenyl phosphate; dibutyl phenyl phosphate; and triphenyl phosphate may cause OPICN or contribute to its occurrence. [260]

Testing to date of TCP in relation to the exposure route onboard aircraft has been seriously flawed. Testing has not replicated actual exposure scenarios occurring within aviation, where occupants possibly pregnant, are inhaling the heated by-products of heated engine oil in a reduced pressure environment. Furthermore testing is focussed on an inappropriate end point of exposure. Serious neurological damage may occur prior to the generation of OPIDN, an extreme endpoint of OP exposure.

Passengers and crews who are exposed to contaminated air and who have developed medical problems do not present with symptoms similar to OPIDN seen in rats and hens and therefore basing testing solely on OPIDN is not ensuring that those exposed will not have suffered significant neurological damage. [396] Following exposure to contaminated air passengers and crews are reporting medical problems (refer to the health section in this thesis) that include neurological problems as well as lung injuries. [185,397,398,399,400,401] Crews are additionally reporting a number of neuropsychological problems with evidence of under functioning on tests associated with psychomotor speed, executive functioning and attention. [402,403] Recent research has confirmed neuropsychological abnormalities in sheep farmers exposed to low levels of OP pesticides suggesting theat the findings may have implications for other occupational groups exposed to OPs including aviation workers (military, pilots and cabincrew) and Gulf War veterans. [404]

Regulations state that *‘if in practice, the toxic effect of a substance on humans is, or is likely to be different from that suggested by the results of animal testing, then the substance should be classified according to its toxicity in humans.’*

[94,103] This is especially relevant considering the known TOCP effects mentioned previously. As no crew member or passenger, has been contacted by the oil manufacturers seeking access to their medical reports or symptoms following a contaminated air exposure event; it doesn't appear either of these regulations is being adhered to.

Given the common practice within the aviation industry of refering solely to the toxicity and quantitiy of TOCP, the equivalent toxicity of the OCP isomers has been significantly underestimated by a factor of up to 30,731. [182] This is due to the very common practice of sole reference to the least toxic of the OCP isomers, Triorthocresyl phosphate (TOCP), while excluding the higher quantities and toxicity of the other OCP isomers, MOCP and DOCP. Given the increased toxicity of the mono ortho-cresyl and di ortho-cresyl isomers [257] over TOCP and based on the quantity of the isomers in the TCP, [183] Table 2-6 shows the significant underestimation of toxicity of the OCP isomers. [182]

Table 2-6: Tricresyl Phosphate: Toxicity of Isomers

Isomer	Concentration (ppm)	Relative Toxicity	Equivalent Toxicity
TOCP	0.005	1	1 ×
DOCP	6	5	30 ×
MOCP	3070	10	30700 ×
		Total	**30731 ×**

Other effects of TCP/TOCP exposure have been known for over 20 years. TOCP and TCP containing <0.1% TOCP are known male rat reproductive toxicants, this was highlighted by Somkuti in 1991, and by Carlton in 1986 and 1987. [405,406,407] Reproductive toxicity was again reported in 1994 by Latendresse from the US Navy. [408] Long term fertility studies in crews being exposed to contaminated air have never been properly investigated. However the French oil manufacturer NYCO after undertaking studies on TCP and TIPP, upgraded the warnings on their oil MSDS to reflect reproductive concerns.

It was acknowledged in 1982 that TCP exposures may cause respiratory tract and mucous membrane irritation in addition to other symptoms. [409]

In 1992 Banerjee reported a suppression of humoral and cell-mediated immune responses in rats exposed to sub-toxic doses of TCP. This suppression was found to increase in a dose dependent pattern. Consequently, an adverse effect of TCP on immune function could render the host more vulnerable to various pathogens. [410] Based on the animal model studies, it is reasonable to assume that TCP exposures will also likely impact the immune system of individuals exposed onboard an aircraft. This issue has yet to be properly investigated.

It is important to realise that with OP exposures many OP nerve agents can cause cumulative effects, so a threshold may be reached either through a single exposure or through repeated exposures leading to a cumulative toxicity.

In the last five years research has shown that exposures to TCP and TOCP at levels significantly below that required to trigger OPIDN are having other significant effects including the modification of gene expression, which is of significant concern. [411,412,413,414,415] This further re-affirms the need to test the oil product whilst looking for the appropriate end points of exposure, if exposures cannot be prevented by the aviation industry.

Recent research into biomarkers for exposure to TCP used in jet engine oils concludes that toxic gases or oil mists in cabin air may form adducts on plasma butrylcholinesterase and albumin detectable by mass spectrometry. [322] The research postulates that if aerotoxic syndrome is caused by the toxic metabolite of TOCP, CBDP, the levels of exposure are likely relatively low as the symptomology is different from the paralysuis (OPIDN) observed on high dose exposure. [322]

Despite all of the above data and the emerging thinking in relation to TCP exposures, Mobil stated in 2000 that *'Transient gastrointestinal effects and OPIDN are the only toxic effects that we accept as being caused by human exposure to TCP.'* [277] Additionally Mobil stated *'There is no record of a jet oil formulated with modern conventional TCP causing human* toxicity'. [183,226]

The main constituent of most jet engine oils are base stocks consisting of esters of pentaerythritol (PE) (CAS no. 115-77-5) and dipentaerythritol (CAS no. 126-58-9) and trimethylolpropane ester (TMP) in some cases. There is little toxicity data on this group of chemicals, but generally these molecules are considered to have little toxicity. [416] Some oils use a base stock largely consisting of the trimethylolpropane ester (TMP/TMPE)(CAS no. 77-99-6). [417] TMP showed modertate toxicity in testing, however little data is available. Esters used in the base stocks of synthetic turbine oil and are combined with carboxylic acids during the synthesis process, however thermal decomposition causes turbine oil to revert back to esters and carboxylic acids. [313] The carboxylic acids have very low odour thresholds and can be irritating and have a smell characteristic of dirty socks. [313] The organic acids, known irritants are also described as acrid or body odour and are seen as *'not dissimilar to the descriptions of cabin odours'* in some of the identified reports. [252] According to recent pyrolysis studies the major change in oil constituents from new to used and cold to thermally degraded oil was a small increase in the percentage of low molecular weight organic acids and esters. [252] Earlier 1954 USAF studies found that: [146,147]

- Oil fogs formed at 400 - 550^{o}F were *'much less toxic than those formed at 600^{o}F'* with toxicity related to time to death. The toxicity of the products arising from the thermal decomposition of the synthetic lubricant was derived largely from the principal ingredient, the base stock and only slightly from the mixed TCP isomers while the products of thermal decomposition were found to be *'much more toxic'* than the undecomposed (TCP) material. *'In the case of the esters… aldehydes, carbonyls, carbon monoxide and undecomposed particulate matter were found in the atmosphere of the chamber. In the case of the tricresyl phosphate, free cresols, undecomposed tricresyl phosphate and carbon monoxide were found.'* The fogs produced pneumonitis and degenerative changes of the brain, liver and kidneys.

Lubricants that are composed principally of TCP and TMP have been shown to form a potent neurotoxin trimethylopropane phosphate (TMPP) during pyrolysis and or combustion. [361] TMPP is thought to irreversibly inhibit the GABA mediated inhibitory response and thereby produce epileptiform seizures. [202] The potent neurotoxic chemical has been found to occur at temperatures of 250°C to 750°C under certain conditions. [225] Difficulties in detecting TMPP have been noted. [224,418] The concern was great enough for the US Navy to recommend removing synthetic oil using TMP in the base stock from it's inventory and to suggest all polyol ester based synthetic jet oils in the US navy be tested for toxic by-product production. [224] Additionally it was suggested that research should be initiated for *'the overall toxicity of combined combustion by-products rather than for any individual combustion product.'* [224]

2.6.4 Genetic variability and susceptibility

When the full sequencing of the human genome was completed in 2003 it confirmed the tremendous genetic variability present in the human population. An estimated 1.4 million specific differences, or polymorphisms, in the human genetic code have been identified. Every polymorphism on a human gene is a DNA sequence that differs from one person to the next. Each of these 1.4 million polymorphisms represents a chance for a person to be at risk for a particular disease or uniquely susceptible to the harmful effects of a particular chemical. [419,420,421] This variability will exist among pilots, crew and passengers, especially, the very young passengers or developing foetuses. This has been recognized by SAE and ASHRAE, amongst others. [24,33,322]

Some individuals and sub-populations can also be at increased risk because they are more susceptible to the adverse effects of a given exposure. Among the potential causes of enhanced susceptibility apart from inherent genetic variability are age, gender, pre-existing disease (e.g. diabetes, asthma), inadequate diet, occupational, environmental or lifestyle factors (e.g. smoking), stress and inadequate access to health care. [422]

Foreign chemicals or drugs are also called xenobiotics and cytochrome P450s play an important role in xenobiotic metabolism, especially for lipophilic drugs. The P450 role in converting TOCP to CBDP was discovered over 50 years ago. P450 proteins are categorised into families and subfamilies by their sequence similarities. There are now more than 2500 cytochrome P450 sequences known. A polymorphism is a difference in DNA sequence found at 1% or higher in a population. These differences in DNA sequence can lead to differences in drug metabolism, so they are important features of P450 genes in humans and play a key role in understanding differing individual responses to chemical exposures. For instance the P450 *‘CYP2C19’* has a polymorphism that changes the enzyme's ability to metabolise mephenytoin (a marker drug). In Caucasians, the polymorphism for the poor metaboliser phenotype is only seen in 3% of the population. However, it is seen in 20% of the Asian population. Consequently some drugs that have a narrow range of effective dose before they become toxic might be overdosed in a poor metaboliser. This is also relevant to chemical exposures as individuals may have a wide variation in ability to detoxify a contaminated air exposure.

As an example PON 1 status modulates the interactive toxicity of selected OP compounds thereby indicating PON 1 status can have a major influence on specific detoxicifcation of selected OP compounds. [351]

There is still much to learn about the factors involved in determining sensitivity to specific chemicals and OP compounds. As researchers learn more about genetic factors that contribute to differences in chemical sensitivity, their findings may be used to improve the accuracy of chemical risk assessments that are applied in the development of regulatory decisions for the protection of public health. [423]

2.6.5 Synergistic effect

The *‘Synergistic Effect’* of exposure to multiple compounds needs to considered. Sometimes the combined effect of multiple exposures is considerably greater than the sum of the effects from the individual components. This phenomenon can be one of synergism or potentiation. Synergism occurs when both chemicals have an effect individually and a more than additive effect when together. Potentiation is when one chemical has an effect but the second chemical does not but enhances the effect of the former chemical on combined exposure.

In relation to contaminated air exposures a Honeywell representative stated *‘Contaminant levels may be well below recommended levels in currently accepted safety standards yet generate complaints, because they act in synergy with other contaminants or because some standards may be outdated and not have incorporated more recent scientific and medical evidence.’* [255]

At present the understanding of interaction effects is incomplete but the synergistic effects of exposure were made very clear to the aviation industry in 1999. In flight over Sweden one evening both pilots became incapacitated following inhalation of a complex cocktail of chemicals, all subsequently reported by the engine manufacturer to be below their individual exposure levels. [139] The knowledge that such effects can occur is reason to maintain the concentrations of individual substances as low as is practicable under complex exposure conditions. [97] However the synergistic effects between TCP and pesticide permethrins has been recognized. [284] There is also some aviation industry recognition that the summation principle may apply in certain cicumstances, yet there may be synergism between contaminants, eventhough the individual chemical concentration may well be less than the published threshold values. [313]

2.6.6 Carcinogen exposure

The effects of exposure to any hazardous substance depends on the dose, the duration, method of exposure, personal traits and habits, and whether other chemicals are present and P450 levels. Crews blood tested following exposure to contaminated air are reporting confirmed exposure to a number of reported human carcinogens such as the heavy metals beryllium and nickel. [424,425] Beryllium and nickel are used in the manufacture of certain jet engine parts and components.

Other compounds found during a contaminated air event which are known or suspected carcinogens include 1,1,1-trichloroethane; 1,2-dibromoethane; 1,2-dichloroethane; 1,2-dichloropropane, benzene and formaldehyde to name a few.

Little data is available to document levels of exposure during contaminated air events. Such events have not yet been measured in aircraft.

2.6.7 Carbon monoxide

Carbon monoxide (CO) may be produced as a by-product of incomplete combustion and may be generated due to thermal decomposition of contaminants entering the bleed air supply system, such as oil hydraulic fluids or deicing fluids. [313] The CO concentration generated will be dependent upon many factors, such as airflow, the quantity of the contaminant, and the temperature of the bleed air and surfaces in contact with the contaminant. [313]

CO exposure is also known to be occurring and yet aircraft have no carbon monoxide detectors. Carbon monoxide is an odourless, colourless and toxic gas. Because it is impossible to see, taste or smell the toxic fumes. The effects of CO exposure can vary greatly from person to person depending on age, overall health and the concentration and length of exposure. Acute symptoms from CO include headaches, confusion, dizziness, nausea, weakness and unconsciousness. Long term (chronic) exposure to low levels of carbon monoxide may produce heart disease and damage to the nervous system. Longer term effects of CO are now known to result in brain damage and cognitive impairments in the absence of lesions and other neuroanatomic markers. [426] Exposure of pregnant women to carbon monoxide may cause low birth rates and nervous system damage to the offspring. [427]

2.6.8 N-phenyl-alpha-naphthylamine (PAN)

N-Phenyl-alpha-naphthylamine (CAS no. 90-30-2) is a lipophilic crystalline solid that is used as an antioxidant in synthetic jet engine oils usually at 1%. Impurities advised by Mobil in PAN include, N-phenyl-2-naphthylamine (PBN) with a CAS number of 135-88-6 reported to be at 0.5% or less and β - naphthylamine (BNA) with a CAS number of 91-59-8 reported to be at 0.005% or less in the PAN in the oil. [215] PBN is category 3 carcinogen whilst BNA which has the molecular formula of C10H9N, is also known as 2-naphthylamine and is a category 1 known and prohibited human bladder carcinogen. [428,429,430,431,432]

These substances were previously listed on the Mobil Jet Oil II 1992 MSDS but were soon removed because Mobil thought the information was not meaningful. [215] Mobil thought it could lead to undue concern due to the presence of carcinogens. β-naphthaylamine is possibly in the oil in too lower amounts to be subject to the hazardous substances regulations; however, it is listed as a prohibited Schedule 1 substance under the Australian hazardous substances regulations with very limited scope for exposure. Exposure is only permitted in research and analysis unless present at very low levels as a contaminant and then all worker contact is to be avoided. In the UK, it appears in Schedule 2 of the Control of Substances Hazardous to Health Regulations (COSHH) 1999 which prohibits its *'manufacture and use for all purposes'*.

PAN is not listed on the Australian list of hazardous substances; however, it has been shown to be a strong skin sensitiser in guinea pig tests which were later confirmed in human studies. [290,291,292,293] Short term effects of PAN exposure are listed as methaemoglobin production in the blood while some authorities list PAN as a skin, eye and mucous membrane irritant. [234,258,285] Acute hazards/Symptoms of Inhalation exposure include: blue lips or finger nails, blue skin, confusion, convulsions, dizziness, headache, nausea and unconsciousness. [258] Workers exposed to antirust oils containing 0.5% PAN reported a variety of tumors, for which N-Phenyl-alpha-naphthylamine was thought likely to be responsible. [433] It has been advised that, based upon the limited data on carcinogenicity of PAN, the established sensitisation properties of PAN and the carcinogenic properties of contaminants of PAN, that exposure to this substance should be avoided. Additionally, limited data indicate that the kidneys and liver are the main target organs following ingestion. [293]

2.6.9 Other considerations

In 2006, a wide selection of UK pilots undertook advanced blood testing which apart from revealing the organophosphate TCP in blood cell membranes also revealed the presence as DNA adducts of heavy metals used in the aviation industry such as Nickel and Beryllium. [434]

While many seek to look at the individual substances, there is considerable data relating to oil mists. For example, oil mists consisting of aerosols released into the air or vapours condensed into the atmosphere are respirable and particulate matter (<0.5 μm in size), which can reach the lungs with larger particles condensing into the nasal and bronchial passageways and then available to the gastrointestinal tract. Dermal exposure can lead to increased levels of systemic toxicity. [270] Special concerns relate to small sized aerosols (<0.3 μm) as respirable/alveolar particles. [33]

A number of organisations like the CAA have confirmed that they have never researched the long-term effects of chronic neurotoxicity, the contaminants present in the fumes or the acute effects passengers and crews were experiencing. [435,436]

A Worksafe Australia employee advised Mobil, *'To clarify the derivation of the statement 'not hazardous by Worksafe criteria', I would suggest the following words be added; 'as determined by Mobil, based on toxicity test data on the product… this will avoid any confusion as to the source of the non hazardous statement.'* [281]

In 2009 a French oil manufacturer changed its engine oil lubricant MSDS sheets to reflect current research with the MSDS stating: *'Product may decompose at elevated temperatures or under fire conditions and produce harmful gases or vapours. Vapours or mist of heated product may be harmful by inhalation... R 63.G3 Possible risk of harm to the unborn child. R 62.F3 Possible risk of impaired fertility.'* [223]

The MSDS change was then followed by a letter to EASA where the manufacturer NYCO highlighted that its research to better understand the relation between chemical structure and neurotoxicity (measured by the level of irreversible inhibition of BChE) led it to conclude that *'commercial TCP (as used in most jet engine oils) presents a non-negligible potential of BChE'* and it's oil additive TIPP did not present a significant improvement over TCP. [222] The research revealed that another potential antiwear OP additive induced a much lower inhibition of BChE and that *'Consequently, Nyco has filed a patent application concerning these new oil formulations having potentially an overall reduced neurotoxicity by several orders of magnitudes, comparatively to oils containing the same concentration of TCP'.* Furthermore NYCO stated *'As an additional health benefit, this oil is also free of phenyl-napthylamine, a molecule used as anti-oxidant that is present is most existing engine oils, and cause of some concerns.'* [222]

Finally when assessing toxicity to mixtures, a UK body recently advised: *'There are several difficulties associated with risk assessments of chemical mixtures. One difficulty in assessing the potential effects of exposure to mixtures of chemicals present at low concentrations is that most experimental data on the effects of exposure to chemical mixtures have been obtained from studies using relatively high levels of exposure. The type of combined action or interaction* *found at clearly toxic effect levels may not predict what will happen at lower levels. ...Hence, there could be many uncertainties in the hazard assessment and estimated dose-response relationships for chemical mixtures.'* [321]

2.6.10 To Summarise

Despite the accepted fact that occurrences of contaminated air are occurring and individuals and their physicians are reporting adverse health effects as a consequence of such exposures; no industry stakeholder has sought to better understand these issues. No airline, regulator, engine manufacturer, health and safety national body, aircraft manufacturer or lubricant manufacturer attempted to appropriately investigate the toxicology of exposure to heated engine oils until the French oil company NYCO did so. NYCO has openly investigated not only the cutting edge gene expression impact of exposure to engine oils and their toxic antiwear additive; but has sought to seek out less toxic additives for future use. This is ironic as it was NYCO who in the 1970s replaced TCP from all their aviation lubricants at the recommendation of the French health ministry. [222]

With time, like previously with smoking or asbestosis the toxicological impact of exposure to contaminated air is becoming better understood. Only adequate funding and an extensive multi discipline research project provide a better understanding of the toxicological impact of exposure. In the interim it is necessary to rely on common sense, which indicates, that inhaling heated engine oils is to be avoided and therefore take steps to prevent individuals being exposed.

2.7 Flight Safety Aspects of Contaminated Air

2.7.1 Introduction - Review of existing knowledge

Although there has been extensive debate over many years on whether contaminated air consisting of oil or hydraulic fumes and/or fluid leaking into the cabin air supply constitutes a long term health risk, few today attempt to argue there is no risk to flight safety. How the industry mitigates and addresses this potential flight safety issue will be investigated; the changing views over time and lack of common policy and procedures or enforcement of such policies and procedures will be looked at in depth.

In 1953 the Aero Medical Association (AsMA) clearly stated that pyrolyzed oil *'can contain irritant and toxic aldehydes and other dangerously toxic products of incomplete combustion… Even a small degree of bodily impairment from toxic gases would lead to increased pilot error and so be hazardous in aviation.'* [144] In Australia, the introduction of fumes and odours into the cabin environment following an engine defect, was seen by the Australian Transport Safety Bureau (ATSB) as constituting a *'possible safety deficiency.'* [437] A safety deficiency is a situation that can be '*reasonably be regarded as having the potential to affect adversely the safety of aviation.'* [438]

Although many small piston engine recreational aircraft have basic carbon monoxide detectors fitted, currently there is no regulatory requirement for commercial jet or turboprop aircraft to have contaminated air detection systems fitted. Therefore, the flight crew's ability to smell is the only form of detection system, yet many chemicals are odourless such as carbon monoxide and pilots do not need to have a sense of smell to hold a medical certificate to fly. Additionally, after 3 minutes of exposure to an odorant, the subject's perceived intensity of the odorant is reduced by about 75%. [439] This clear safety failing combined with the knowledge that the bleed air is not filtered, has led a number of organisations such as the Global Cabin Air Quality Executive, politicians and industry bodies to call for the mandatory fitting of contaminated air detection systems on all passenger aircraft. [440,441]

Aircraft contaminated air events fall directly under the responsibility of the national aviation regulations and hence are the responsibility of the national aviation regulators such as the Federal Aviation Administration (FAA), European Aviation Safety Agency (EASA) or the Civil Aviation Safety Authority (CASA) in the Australian case. Regulations related to the requirement for clean air can be traced back to at least 1937. [3,4] The 1953 regulations in the US required that '*All crew compartments shall be ventilated by providing a sufficient amount of outside air to enable crewmembers to perform their work without undue discomfort or fatigue... Ventilating air… shall be free of harmful or hazardous concentrations of gases or vapors.'* [5] These regulations have remained almost unchanged over the years and form the heart of the airworthiness requirements regarding ventilation systems and air quality with an aircraft being unable to fly unless these are met.

There are various regulations that relate to the requirement for clean air on board passenger aircraft, ranging from the reporting requirements, defect identification and rectification, crew fitness to fly, use of emergency procedures to airworthiness and duty of care, even though it is not explicitly identified. Thus, the regulations clearly demonstrate this is an aviation industry responsibility, with the aviation regulators being primarily responsible for aircraft safety, although in some cases a conflict exists with a responsibility to promote air travel. Despite these regulations, over the last five decades there has been a clear pattern of these regulations being ignored or not enforced. There are many reasons for these failures, which will be investigated further.

2.7.2 Contaminated air seen as normal or a nuisance

Pilots and cabin crew are taught about the serious adverse effects of hypoxia on flight safety, however education into the effects of contaminated air exposures are virtually non-existent within the aviation industry. Crews are not aware of the symptoms that might occur as the result of breathing contaminated air or what the toxic chemical mixture is when synthetic jet engine oils containing a mixture of substances, including tricresyl phosphate (TCP) are heated or pyrolised. As such they have no understanding that such symptoms could pose a flight safety risk or could have an adverse effect on health whether short or long-term. Acknowledgments that oil leaks are a function of the way bleed air systems work [33,153,154,155,157] and that all oil seals leak [123] explain why these events are in fact very frequent. Consequently, it is not surprising that crews invariably just assume that contaminated air odours are part of the flying environment. In fact most crews see contaminated air as a nuisance and are unaware of the serious flight safety issues contaminated air can cause and has caused on numerous occasions. [45,442]

British Aerospace clearly highlighted that fumes had been seen as a nuisance and must now be seen as a *'potential'* flight safety issue when stating: [443]

- *'Incidents have been reported involving impaired performance of the flight crew... In the past, oil leaks and cabin/flight deck odours and fumes may have come to be regarded as a nuisance rather than a potential flight safety issue. However, whilst investigations are being carried out, oil leaks and cabin/flight deck odours must be regarded as a potential threat to flight safety, they should not be dismissed as a mere nuisance and should be addressed as soon as possible.'*

The Canadian Transport Safety Bureau report into the 1998 fatal accident of Swissair 111 reported that *'within the aviation industry there has been belief that smoke or odour situations are often a non event, thus further diminishing concern about minor odour events.'* [444]

Many crews have reported contaminated air as a normal part of flying. In fact the Australian Transport Safety Bureau (ATSB) concluded that due to recurring nature of fume events on the BAe 146 they *'may have become 'routine' in the thinking of some operating crew and awareness of the possible risks may have diminished as a result.'* [445] This is highlighted by a contaminated air event in which the outgoing crew failed to report the defect in the aircraft log, rather just advised the incoming crew verbally. [446] In fact, BAe 146 pilots at East West (an Australian airline) in the early 1990s were making passenger announcements on all flights apologising for the *'sweaty socks'* smell. [447] In Europe, DHL advised its pilots in 2007 that fumes at certain stages of flight were normal and the CAA accepted this comment/situation without taking action: [71,72]

- *'...it was not unusual to experience a low concentration of oil fumes... after engine start, during taxi, after take off (especially at full power, top of descent, taxi in. if such fumes become apparent during any of these* *phases of flight and then dissipate, do not report the occurrence, it is normal.'*

Some in the aviation industry dismiss the flight safety hazards that contaminated air poses on flight safety on the basis that contaminated air events occur infrequently, others state that contaminated air events are not always related to oil or hydraulic fumes. Cognisant authorities have clearly stated that oil leakage is the predominant source of the fumes. The ATSB reported the difficulty in generally locating the source of the oil leaks that caused the fumes and that '*the failure of oil seals has been a common factor in the majority of those incidents.'* [448] British Aerospace, Ansett, Rolls Royce, the UK CAA, EASA and many more have all concluded that the majority of fume events are related to engine oil leakage. [39,252,336449,450,451] Further information to support this is available as part of this dissertation.

2.7.3 Incapacitation and impairment

Hypoxia like contaminated air can subtly affect the crew member. Many crews have become impaired, partially incapacitated or incapacitated without knowing it. Others have become completely incapacitated as a result if inhaling contaminated air. Despite there being no contaminated air detection systems for commercial or military aircraft, pilots are not tested to see if they presently have a sense of smell. This is ironic as the human nose is the only form of detection system available and no defence against substances with no smell such as CO or TCP.

There is clear awareness that exposure to oil fumes was known to have caused impairment and possibly incapacitation and fatal crashes in the 1950s and 60s [452] (seen elsewhere in this thesis). However the first known published case of incapacitation occurred in 1977 when a 34 year-old navigator on a US Air National Guard (ANG) Lockheed Hercules transport aircraft was incapacitated. [149] The investigations undertaken by the ANG concluded that the situation resulted from an inhalation exposure to aerosolised or vaporised synthetic lubricating oil, with such fume events reported as not infrequent. The gradual onset of headache, followed by dizziness, nausea, vomiting, incoordination and sweating culminated in difficulty standing after landing. The report noted that disturbances in the mental and neuromuscular function of aircraft flight personnel by any influence, is of obvious concern and significance. The report advised that further investigation into *'the potential hazards from inhalation of synthetic oil fumes that are generated by these circumstances is definitely warranted.'* Thirty three years later this research has still not, in reality, taken place.

In the 1981 it was reported that the National Transport Safety Bureau (NTSB) were investigating about a dozen aircraft crashes on a particular type of turboprop aircraft in which the questioned raised was if *'toxic oil additives or by-products of scorched engine oil are leaking from the engines into the cabin air sup*ply.' [364,453] In 1997 a well-known incident took place in which the captain was incapacitated and the check captain was impaired on descent into Melbourne, Australia due to a previously ignored oil leak. [437]

Several other examples (out of many) of the consequences of the flight safety problems include the following:

- The pilot in command of a BAe 146 reported that the smell of oil coming through the air supply was far worse than usual with the passengers and flight attendants complaining bitterly of the smell. The First Officer also complained of the smell, experienced worsening red/weeping eyes. On final approach to land the Captain slowly became aware of feeling, *'as drunk as a skunk'* as if having consumed about 6 scotches. The captain reported having trouble judging the distance to land with everything seeming, *'wonky'* including the runway. The Captain reported that the symptoms similar to intoxication, removed all consideration of handing over control to the First Officer. The pilot grounded the aircraft and stated that further flight would not even be considered until fresh air was obtained to, *'sober up.'* [454]
- On a Boeing 757 the crew smelt *'fumes'* (oil fumes) on start up. Before take off the co-pilot felt *'strange/vague'* but then recovered and take off was normal. A few minutes into the flight both flight crew suffered a slight headache and mild nausea. All symptoms cleared by about 20 minutes after take off. Oxygen was not used as it was not considered necessary; however after the flight both pilots reported headaches and nausea

persisting. The next day, the Captain felt OK but the co-pilot who had experienced another exposure event 2 days prior felt very fatigued, dizzy, nauseous, and vague, with a loss of balance. The Co-pilot rang the airline medical department, which stated they had lots of calls on contaminated air and that a lot of this was, 'psychosomatic' and would not allow the pilot to speak to a doctor. On investigation, one of the engines forward bearing feed and scavenge tubes were found leaking and the seals were replaced. The leaking oil had contaminated the Auxiliary Power Unit (APU). [455]

- Oily smell on outbound sector. On return sector crew unaware that they were becoming partially incapacitated/P1 (Captain) then forgot to slow a/c. The AAIB summary of the event stated *'Oily metallic smell had also been evident during previous sector. On this occasion, numerous ATC calls were missed, prompting ATC to ask a/c if everything was all right. P1 then forgot to slow a/c during approach until reminded to do so at 3.7d (miles). Crew unaware that they were becoming partially incapacitated.'* [455]

There are many thousands of reports available showing aircrew experiencing adverse effects related to suspected bleed air contamination, with many more cited by the author. [456] These can range from more minor adverse effects such as headaches, metallic taste or watery eyes, through to full and sometimes subtle incapacitation. Of the 265 known reported contaminated air events in the UK in 2005, 32% show some degree of impairment to the aircrew, while 20% record some degree of impairment to at least 1 pilot with 9% recording adverse effects in both pilots. [451] A UK AAIB review of the CAA database found that 40 of 153 (26%) reports of which 119 resulted *'probably'* from contaminated air, showed *'adverse physiological effects on one or both pilots, in some cases severe.'* [23] The Australian ATSB report toxic fumes as the second most common cause of pilot incapacitation accounting for 12% of incapacitations. [457] However it is very common for many in the aviation industry to ignore the evidence of under-reporting, or the level of impairment in the reports that are available. [451] The CAA incorrectly advised that the *'number of events where impairment has been reported remains low.'* [458]

However, short term effects are clearly acknowledged as being associated with oil fume inhalation. [337,459] Many have stated that the substances can have an irritant effect only, including the CAA, [252] while a UK airline stated that the *'noxious substances'* if released into the cabin they would likely have an irritant effect rather than a toxic effect. [335]

Of 414 recorded Australian BAe 146 contaminated air events, of which most were acknowledged as oil related, 83% record adverse effects being experienced in most cases by the aircrew including pilots.[†] [21,336,449,460] 95% of these reports were from Ansett which stated it encouraged its crews to report oil fume events. One such report noted that the pilot had to sit in the terminal to *'recover'* before the next flight. Such reported experiences were not uncommon to the author.

There is also a variance in what is actually reported. This is due to both a limited but changing knowledge of the effects of fumes and willingness to report on a subject little understood and which is not favoured by the industry. For example in 1999 two Swedish BAe 146 pilots were incapacitated in flight, at night, due to leaking oil fumes, that were not detectable by smell, yet the report stated that it was *'probably polluted cabin air'* and that the captain had difficulty with physiological motor responses and in focusing. The captain has reported that he and his co-pilot were in fact *'paralyzed for a number of minutes'* and the reports showing oil containing TCP and oil degradation by-products were found to have leaked into the cabin air. [139,249,250,461,462] Adverse effects had in fact been experienced by the cabin crew on the 2 previous flights, as well as in the third flight in which the pilots became impaired.

The situation of official reports containing limited information on crew impairment and the subsequent impact on flight safety continues. However, a 2006 Swiss Air Accident Board report, for the first time clearly connected oil fumes to crew impairment without any hesitation. The report into a flight that suffered a contaminated air event whilst flying to Zurich stated: [357]

[†] For the purposes of this thesis, aircrew includes flight crew (pilots, flight engineers and so forth), and cabin crew (pursers, flight attendants and so forth).

- *'The serious incident is attributable to the fact that on approach to Zurich Airport the cockpit filled with fumes which caused a toxic effect, leading to a limited capability of acting of the co-pilot. These fumes were caused by an oil leak as a result of a bearing damage in engine No. 1. The indicators for impending bearing damage were not correctly interpreted before the incident.'*

This particular incident clearly demonstrates a number of problems that have gone on for years, continue to date and highlights the deeply entrenched culture in relation to contaminated air events onboard aircraft. Fumes including *'light white fumes'* were reported on the two previous flights on the same aircraft with oxygen not being used on either occasion. Maintenance actions failed to find any evidence of oil after the first incident following a visible inspection and engine run. Engineering had simply released the aircraft back into service with a request for the crews to report fumes further. After the second incident, oil was noted by maintenance, which led to the suspected air conditioning pack being listed as inoperative under the MEL system. Further maintenance actions took place along with increased oil consumption noted. However these actions failed to identify or rectify the problem and were later listed as inadequate due to workload pressure on the mechanic in charge, with the aircraft cleared as fully operational with a report in the aircraft log as '*PLEASE REPORT ANY SMELL OR DUST OF OIL FROM AIRCONDITIONING.'*

On the following flight, in which the copilot was overcome by fumes, the captain failed to use oxygen at any stage despite it being a requirement in the checklist and whilst knowing that the copilot's condition had deteriorated when he temporarily removed his mask. The report noted that the maintenance (despite company and manufacturer written procedures) request for the crew to report fumes further indicated that *'those responsible in the line maintenance were not aware of the effects this phenomenon can have inside a cockpit.'* [357]

The Zurich incident is just one of many that clearly highlights the very serious flaws currently present throughout the whole aviation system. Flaws that range from aircraft design, inadequate procedural and reporting systems, poor maintenance practices, to crews' continued failure to use oxygen when the air is contaminated. Until these flaws are addressed, crew impairments and incapacitations will continue. As an example a recent air accident investigation report involving an A319 reported serious crew impairment in flight (pilots and all cabin crew) with many passengers appearing to be drowsy and asleep, however no detectable fumes were present. [463] Investigations undertaken by the airline and manufacturer that found limited contaminants that were dismissed as being below set standards and as such a toxic contaminants and oil were dismissed as a cause. The report clearly highlighted that contaminant sensors would have alerted the crew if contaminants had been present, however it was suggested that such technology was not available and posed technical difficulties according to the aviation industry and could not be *'realistically fitted'* to commercial aircraft. Therefore no regulator required monitors to be fitted. The Irish investigation bureau saw no benefit in making such recommendations to EASA as the regulator was already investigating cabin air quality. [39,463]

2.7.4 Reporting and rectification

All suspected contaminated air events are required to be reported in the aircraft technical log immediately after the flight where the defect is noted. Published figures of oil fume related events show that in Australia such reports were recorded in 1.5% of flights, while in the UK oil fumes were stated to occur in 1% of flights. [21,70,336] However it is known that most fume events are not reported at all, as required, with a figure given of less than 4% of fume events being reported. [65,66,400,464] Additionally, there is no requirement for aircrews to report adverse health effects as part of a fume event report. Therefore, despite extensive data showing impairment in flight is not rare, reported events will in fact be a very small fraction of actual contaminated events with or without impairment taking place. It seems logical that the more serious cases of incapacitation or more serious smoke and fume events as opposed to fumes alone are more likely to be reported, however, this has not always been the case. Additionally reports are not always passed on to the correct authorities or made publicly available.

Another problem identified is that contaminated air events are well documented, as often not being easy to identify with the engineering procedures that have taken place. Reports are known to be dismissed by engineering as *'not safety of* *flight,' 'no fault found' or 'please report further'* with the fault often identified after further reports and more thorough investigations. [11,45,437,451,442,465] In addition to the Australian BAe 146 *'NJF'* 1997 event, where the oil fumes defect was signed off as *'rectify at company convenience'*, one of the many UK events highlights the problem well. [437,451,466] Fumes were reported on a Boeing 757 over 2 days with no Air Safety Report (ASR) or CAA Mandatory Occurrence report being completed as required. The engineers on the 2nd day requested the crews to *'report further,'* with a further incident occuring the following day, deemed by the AAIB to be a serious incident with an oily burning smell reported, a PAN emergency being declared and the aircraft return to base followed by a subsequent aircraft change. [85,466]

To address the need to collate information on all contaminated air events, the Swedish (SHK) Board of Accident Investigation called for the setting up of an international database of events in 2001 to record all contaminated air incidents. [139] This has yet to occur.

Clearly there are many aviation regulations that show all contaminated air events are required to be reported to the operator via the aircraft technical log and the regulators. There is also a clear line of regulations relating to the identification and rectification of such defects. Aviation regulations related to contaminated air in all cases relate to flight safety and therefore oil or hydraulic fumes, cannot be dismissed as not being a flight safety issue.

2.7.5 Emergency checklists and initial crew responses

Checklists play an important part in the contaminated air debate and clearly demonstrate that this is an important flight safety issue. A number of varying checklists are outlined below setting out the mandatory memory items. An early version of the British Aerospace BAe 146 emergency checklist is shown in Figure 2-15. [467]

The checklist refers to SMOKE or FIRE, with no mention of *'contaminated air'* or *'fumes'.* The lack of specific guidance in the emergency checklists to the crews as to what actions to take during contaminated air events or suspected contaminated air events resulted in most pilots not taking any action at all when contaminated air events were occurring. The BAe 146 checklist was changed in

2001 to reflect the need to use oxygen when fumes were present in addition to smoke or fire. [468]

Figure 2-15: BAe 146 - Smoke or Fire on Flight Deck Checklist pre 2001

SMOKE OR FIRE ON FLIGHT DECK OR IN CABIN – ANY SOURCE	
Oxygen Masks ..……………….	Crew don, EMERGENCY
Smoke Goggles ..……………...	Crew don
Crew Communications ……….	Establish

In more recent years the term *'contaminated air'* has been added to some checklists but this has not been properly regulated or enforced. Some airlines even have different checklist emphasis on the same aircraft type. The Boeing 747-400 checklist for *'Airline A'* (Figure 2-16) has the emphasis of, *'SMOKE FUMES FROM AIR CONDITIONING and SUSPECTED CONTAMINATED AIR*.'

Figure 2-16: 'Airline A' Boeing 747-400 - Smoke Fumes From Air Conditioning and Suspected Contaminated Air Checklist

SMOKE/FUMES FROM AIR CONDITIONING and SUSPECTED CONTAMINATED AIR	
Oxygen Masks ..……………….	On
Crew Communications ……….	Re-establish

In contrast, as of 2008, the older emphasis was still found on the *'Airline B'* (Figure 2-17) Boeing 747-400, of, *'SMOKE/FUMES AIR CONDITIONING'* followed by the comment of, *'Condition: A concentration of air conditioning smoke/fumes is identified.'* The problem with airline B's checklist is that many pilots would assume if they could not positively *'identify'* fumes they would not have use the checklist or oxygen.

Figure 2-17: 'Airline B' Boeing 747-400 - Smoke/Fumes Air Conditioning Checklist

SMOKE/FUMES AIR CONDITIONING

Condition: A concentration of air conditioning smoke/fumes is identified.

Oxygen Masks ..………………	On
Crew Communications ……….	Establish

Checklist variations also exist between operators of the Boeing B757. One operator's checklist for *'Smoke Fumes from Air Conditioning and Suspected Contaminated Air'* requires the use of emergency oxygen whilst another B757 operator's checklist [26] for *'Smoke or Fumes – Air conditioning'* calls for oxygen use only *'if required'* and if smoke or fumes are actually *'identified.'*

As of 2009 the key words of, *'SMOKE OR FUMES FROM AIR CONDITIONING and SUSPECTED CONTAMINATED AIR'* were still missing from numerous aircraft types such the BAe 146, Embraer Emb-145, Dash 8 Q400 and the Airbus A320. Some aircraft manufacturers such as Airbus do not require crews to immediately use oxygen in smoke or fume events.

The A320 checklist from 'Airline A' (Figure 2-18) in 2007 directed crews to use oxygen, *'if required'* and only after numerous other procedures have been completed. This raises serious flight safety questions as the effects of subtle incapacitation and hypoxia have been demonstrated on many occasions with contaminated air events.

Figure 2-18: ‘Airline A’ Airbus A320 - Smoke/fumes/avionics smoke checklist

SMOKE/FUMES/AVIONICS SMOKE

Land ASAP

If perceptible smoke apply immediately

- BLOWER …………………..............	OVRD
- EXTRACT…………..……………….	OVRD
- CAB FANS…………..……………….	OFF
- GALLEY……………………………..	OFF
- SIGNS……………….……………	ON
- COCKPIT/CABIN COM…………….	ESTABLISH

IF REQUIRED

- CREW OXY MASK……………….. ON 100%/EMERG

Etc.

The recent move towards a single integrated checklist template to be used globally for smoke fume and fire situations is welcomed. [469] However in a smoke fire fumes (SFF) event it is left up to the pilots/airlines as to whether oxygen masks are required as an initial action or whether it should be determined on a case by case event or by the operator. Additionally the checklist heading of *‘smoke in cabin and/or flight deck’* is not appropriate as smoke/fumes is considered the key phrase. The checklist template states that the *‘smoke’* checklist covers *‘smoke, fire or fumes*,’ however the reality is that without the term fumes in the checklist heading, oxygen is unlikely to be used as has been the case over many years. The CAA recently advised it disagreed with the Airbus decision to action various items before the use of oxygen if required. [470] The CAA correctly advised operators to require flight crews to don oxygen masks as the first action in the event of smoke or fumes in the flight deck.

The UK Government in 2004 and in 2005 advised that oxygen was required to be used, as a precautionary measure, in all cases of suspected contaminated air irrespective of the severity of the event. [42,471] Aircraft manufacturers design aircraft with emergency oxygen as an integral part of the design an aircraft. The UK CAA have published several Flight Operations Divisions Communications (FODCOM) over the years, all clearly advising that pilots are required to use oxygen if they suspect the air is contaminated. [472] Despite guidance and access to emergency oxygen, pilots still fail to use oxygen when the air is suspected to be contaminated in the majority of events and there is still no common logic within emergency checklists in connection with a contaminated air event, resulting in flight safety being compromised. An extensive review of UK contaminated air events found that oxygen was used by one pilot in 4% of the events, with both pilots in 12% of the events only and often for temporary duration only. [451]

Incidents have indicated that crews are not always fully alert to the possibility of air contamination on aircraft and have not always taken the most appropriate action and have regarded these events as a nuisance rather than a hazard, although their reactions and reported symptoms had been somewhat varied. [85] The frequent occurrence and *'familiarity'* to oil fumes on some aircraft types, has led to fumes being seen as *'routine'* with a diminished awareness of the possible risks. [445] In a well documented case in 2003, the pilots decision to use oxygen after suspected exposure to oil fumes occurred was seen as wise, as the crews *'well-being and judgement can be affected by exposure to engine oil fumes'* and as such the degree of risk can be increased should workload increase, which it significantly did in this instance. [165] However, a 2009 AAIB report clearly shows pilots still failing to use oxygen as directed by the CAA. [26,472] In this case the B757 checklist used by the particular operator stated that oxygen was the first action *'if required,'* thereby leaving the choice with the pilot.

Cabin crew, unlike the pilots, are not provided with 100% emergency oxygen when fumes are thought to be present. The ATSB advised *'The cabin crew* *oxygen is a, 'diluter or therapeutic' mask type. This design does not provide protection from smoke or fumes as most of the air mixture provided is ambient air. Under certain circumstances involving heavy contamination by fumes, the use of this type of mask might mislead the user into a false sense of protection and lead to the possibility of being overcome by the fumes.'* [445] The cabin crew are required to be capable of evacuating an aircraft in 90 seconds and clearly any form of impairment due to contaminated air could prevent this or any other emergency procedures they may be required to carry out, being done so in an expeditious manner. The passengers are also not provided with any form of oxygen when fumes are suspected to be present.

2.7.6 Denial that contaminated air is a flight safety issue

The history of denial by some within the airline industry that *'contaminated air in an aircraft is a flight safety issue'* is a long one. The Australian regulator CASA stated that fumes were not *'an immediate threat to aviation safety'* and *'Oil fumes are more of a health problem than an aircraft technical defect, as not all pilots are affected and there is no mandate to look at health.'* [122,133] CASA clearly stated that contaminated air was well outside its area of expertise and responsibility by stating, *'Toxins in cabin air are an OHS issue and not responsibility of the Aviation Regulator which is responsible aviation safety involving short and medium term effects on safety.'* [121] CASA then incorrectly advised in 2002 that there had been no requirement to report oil fume events to CASA, however it then changed its mind and correctly advised in 2004 that all oil fume events were reportable as they were categorised as aircraft *'major defects.'* [73,132] A *'major defect'* is a defect that *'may affect the safety of the aircraft or cause the aircraft to become a danger to person or property.'* [46,47] British Aerospace advised the Australian Senate Inquiry that just as CASA had advised, aircraft air quality was a highly specialised area for which it was not competent to rule, it was also outside the expertise of the airlines and manufacturers. [123] However, BAe then stated that despite the *'weight of human evidence and suffering'* for which there must be something there, this was not a flight safety risk. [123] In a similar manner, the FAA, in 2005, advised that of 4360 fume/smoke events (level 0 to 2) connected to the engine/APU, all but 3 were viewed as not a serious threat to flight safety or of immediate serious harm to crew or passengers, as the fumes were noticeable with no reported immediate effects or caused minor impairment or injury only to crew and or passengers. [473] The FAA hazard level classification includes: [473,474]

- Level 0: *'Consequences with no safety effect… Malfunctions or failures that result in smoke and/or fumes that have no effect on crew or passengers beyond their notice of the event. The production of smoke or fumes as a consequence of some failures or malfunctions is an expected condition for which the airplane is designed and crew procedures are established and no unsafe condition exist';*
- Level 2: *'Significant Consequences: …Malfunctions or failures that result in smoke or toxic fumes that cause minor impairment or minor injuries to crew and/or passengers';*
- Level 3: *'Serious consequences: Malfunctions or failures that result in smoke or other fumes on the flight deck that result in a serious impairment. Serious impairment includes the loss of crew's ability to see flight deck instrumentation or perform expected flight duties.'*

Apart from the obvious reasons why many have denied responsibility for cabin air contamination being accepted as a safety issue, British Aerospace advised the Australian Senate Inquiry that its aircraft were safe. [34,123] When questioned, it was revealed by BAe that the industry criterion of aircraft safety was that the aircraft got from A to B without having *'had a fatality due to a technical problem.'* [123] This clearly demonstrates the inappropriate view that adherence to the aviation legislation is not part of determining if an aircraft is safe or not. Clearly, in addition to the requirement for the aviation regulations to be met for an aircraft to be deemed safe/airworthy, the Australian Senate Inquiry acknowledged that flight safety and OHS/health could not be separated. Pilots have to be in a suitable state of health to fly, therefore acknowledging the link between crew health and air safety. [21] This is acknowledged in the actual regulations [475] and by many experts. [310,476]

Many contaminated air events are often dismissed by the industry as not safety related and therefore not their concern. [456] The UK CAA advised that feeling unwell or irritation with no impairment involving symptoms such as headaches, nausea, eye, nose or throat irritation was not part of its safety focus. [124,125] This view therefore explains the Government statement that while the Mandatory Occurrence reporting system only related to airworthiness (safety) issues, it regarded many fume events as *'not safety related'* or *'low level events.*' [477,478] This is in total contrast to another answer given stating that all cabin air quality events were reportable events [54] and as such related to flight safety/airworthiness. However, a year later, the CAA advised it did not agree that with regard to oil fume events, there were *'serious flight safety issues'* and that the inclusion of *'lesser events'* did not advance flight safety. [479] The legislation is very clear in that any occurrence, which endangers or if not corrected would endanger an aircraft or it's occupants or any other person must be reported to the regulator, the CAA. [55] Smoke and toxic or noxious fumes are listed as reportable events under the legislation. [53] However, the CAA effectively turned a blind eye by continuing to ignore the reports of contaminated air and crew impairment by stating that, since all UK aircrew took aviation safety very seriously, it was just not possible that the pilots would fail to report fume events involving impairment or fail to meet their duty of care to provide a *'safe operation'* of their aircraft. [479,480] A clear level of confusion within the CAA became apparent when within a very short time frame it stated *'smoke and fume events is not uncommon...', 'flight deck events are rare and of low severity...'* and there was *'no precursors of an emerging 'safety of flight risk.'* [124] This is despite the CAA clearly acknowledging that oil contamination of the air supply could *'exert toxic effects on both crew and passengers.'* [252]

The main airworthiness ventilation regulation, JAR, FAR or EASA 25.831 is the determining factor in identifying whether an aircraft is safe or airworthy. [7,8] The regulation is very clear but almost universally ignored or misused as the industry errs on the side of self interest. [45,475] The presence of contaminants in aircraft air, sufficient to impaircrew capability or the ability of the crew to perform their duties effectively as expected under the legislation, is an example of a breach of these regulations. The section of the regulation relating to *'harmful or hazardous levels of gases or vapours'* is generally subject to misinterpretation. [45] Given that the FAA in 2002 stated that no aircraft is airworthy as detection systems are not fitted to ensure the air is free of contaminants, [18] this glaring safety deficiency cannot be denied.

The UK Government inappropriately advised that contaminated air would make the aircraft unairworthy if the pilots were subsequently incapacitated, ignoring any form of impairment or the mere presence of contaminated air at harmful levels. [42] The CAA's view on the airworthiness is limited to incapacitation due to adverse effects that *'preclude safe flight and landing.'* [41] However, when questioned directly if undue discomfort or fatigue or harmful or hazardous concentrations of gases or vapours had to in all cases be met for an aircraft to be airworthy or safe for flight, the response was *'Yes.'* [481] Despite unequivocal evidence that oil contamination was occurring, [45,252,451] the CAA stated that *'Circumstantial evidence suggested potential contamination of cabin air by abnormal concentrations of noxious gases or vapours',* however the safety risk has been controlled by actions to date. [482] CASA in Australia recognised that part b) of the regulation relating to concentrations of contaminants existed but completely ignored part a) relating to the air not causing undue discomfort and fatigue. [121]

Despite all the evidence many operators continue to state that their aircraft are safe and meet all the regulations. [475] There is an emphasis put on the fact that the airworthiness regulations were met at the original time of the aircraft certification [32,34,35,121,123,449,475,483] many years before, despite that only CO, CO_2 and O_3 were reviewed at the time. [38]

A preliminary briefing by EASA on the outcome of the 2009 EASA A-NPA, [39] advised that airlines, manufacturers and regulators that responded to the A-NPA viewed overall that cabin air contamination events did not present a health or a flight safety issue. [484] It was suggested therefore that EASAs regulatory efforts were best placed elsewhere on issues of safety and technology rather than cabin air.

2.7.7 Acceptance that contaminated air is a flight safety issue

The former director of the Aerospace Medical Association in 1983, when working at the USAF, stated that '*The origin of the fumes in most cases was organic petroleum derivatives which caused a multitude of symptoms including*

CNS dysfunction and mucous membrane irritation... smoke fumes in the cockpit is not a rare event and is a clear threat to flight safety because of acute toxic effects.' [399] Despite such a clear statement, the industry continues to release conflicting advice about whether contaminated air due to oil fumes and hydraulic fluids is a flight safety hazard. This is done despite the clear evidence that such events are well documented and without a doubt a flight safety issue. For example, an Australian operator told it's crews that while the oil fumes were not medically harmful, they could cause headaches and upper respiratory irritation and as such could be very distracting and *'in some cases could cause a flight safety hazard.'* [485] However, as is often the case, this was subsequently denied 2 years later by the airline who later stated cabin air quality was deemed *'not a safety of flight matter.'* This denial culture was also used following the well known 1997 NJF *'Kolver'* incident when 2 of the 3 cockpit crew members became seriously impaired on an approach to Melbourne. [126,437]

A UK operator advised in relation to oil fumes that *'Smells and irritants from burning organic compounds from within the engines are known to produce harmful volatile organic contaminants.'*[486] Further references to those accepting oil fumes can be harmful are found elsewhere in this thesis. A number of investigations analysing the toxicity of the oil, smoke and fumes have taken place over the years. In 1978 the US Air Force (USAF) analyzed smoke/fumes when oils and hydraulic fluids were spilled onto a hot surface as there was concern that the aircraft breathing air could become contaminated and stated: *'Significant quantities of highly toxic compounds were produced.'* [487] In 1983 an FAA study when looking into whether oil fumes could incapacitate pilots, stated that it was *'possible... with an unfiltered line a significant toxicity could be associated with breathing the oil mist.'* [488] The NTSB, despite dismissing oil contamination as an issue related to subtle pilot incapacitation, reported that if *'toxic or anaesthetic byproducts of the oil'* were found to enter the aircraft's environmental system *'such exposures could compromise flight safety and could be a risk on all bleed air aircraft'.* [364]

In addition to the extensive list of Bureau of Air Safety reports related to contaminated air, showing the clear link between inhalation of the fumes and compromised flight safety, there has been a steadily growing list of key actions or admissions clearly demonstrating that cabin air contamination is a flight safety issue. This appears to have followed the well known UK G-JEAK incident in 2000, when both pilots were incapacitated due to oil fumes. [85] Shortly after this incident, the UK CAA issued the first of a succession of FODCOMs due to its awareness that both pilots could become incapacitated by *'toxic fumes'* from engine oil leaking into the air supply. [472] The 2002 FODCOM advised that *'reducing occurrences of oil contamination will also reduce the risk of flight crew incapacitation.'* The 2008 FODCOM reminds crews and operators that the use of emergency oxygen is the first action to be taken in smoke or fume events on the flight deck. [470] However FODCOMS have not always been passed on to the crew. [489] In 2001/2002 BAe Systems issued Service Bulletins clearly stating that while investigations were underway, oil fumes must be regarded as a '*potential threat to flight safety.'* [443] The manufacturer published an *'All Operators Message'* to all aircraft operators of the BAe 146 and Avro RJ-146 regarding actions to be taken when smoke and fumes occur, clearly indicating this was a key safety issue. [155,468] The CAA, closely followed by CASA, issued the first of 3 Airworthiness Directives (AD) related to persistent oil fumes on the BAe 146 and impaired performance. [490,491] ADs are issued to address flight safety related issues, where an unsafe condition exists or is likely to exist. [492,493] The German Civil aviation regulator the LBA issued a similar AD for the BAe 146 in 2003 stating that *'oil leakage… may lead to harmful contamination of the cabin air and cause intoxication of the flight crew'*. [494] The US FAA has issued 3 ADs related to contaminated air. The first relates to hydraulic fumes leaking into the cabin of MD 81-MD90 series aircraft, while the second relates to selected Rolls-Royce/Allison Engines and rapid bearing failure resulting in smoke in the cabin. [495] The 2004 BAe 146 AD issued by the FAA stated very clearly that oil fumes are an air safety issue: [496]

- *'This action is necessary to prevent impairment of the operational skills and abilities of the flight crew caused by the inhalation of agents released from oil or oil breakdown products, which could result in reduced controllability of the airplane. This action is intended to address the identified unsafe condition.'*

While the National Bureaus of Air Safety such as the AAIB and the ATSB are empowered to undertake investigations into incidents so as to improve flight safety, and there is a growing list of such investigations in the UK and Australia; it is clear that only a fraction of the fume and smoke events reported are investigated with most countries failing to investigate such events virtually at all. In the UK for example, the AAIB investigates events where it decides that an incident *'could have been a significant or serious flight safety incident.'* [497] The AAIB advised that in 10 years to 2006, it had investigated 23 contaminated air incidents. The International Civil Aviation Organisation (ICAO) lists as a serious incident, those events requiring emergency use of oxygen by the flight crew, flight crew incapacitation in flight and smoke in the passenger compartment. [74] While taking this definition into account and reviewing the UK contaminated air events database, there are many more than *'23'* contaminated air events that fall into the *'significant or serious flight safety incident'* category. Likewise in Australia, the use of emergency oxygen, smoke or fumes in any part of the aircraft are considered an Immediately Reportable Matter (IRM), based on the reporting criteria of serious incidents according to ICAO. [75]

In 2002, the FAA, in response to the 2002 NRC cabin air report, advised '*No present airplane design fulfils the intent of 25.831 because no airplane design incorporates an air contaminant monitoring system to ensure that the air provided to the occupants is free of hazardous contaminants.'* [18] Regulation 25.831 is the main airworthiness FAR (and EASA) regulation for air ventilation and as such contaminated air is a flight safety issue. In 2007, following another oil fumes event, the AAIB issued recommendations to both the FAA and EASA for the requirement for bleed air monitoring so as to detect smoke or oil mist from the air conditioning. [23] In 2009 the AAIB, referring to yet another oil fumes event, restated the 2 recommendations previously made related to the *'potentially hazardous situation'* faced by crews in identifying oil smoke or fumes and noted that 2 years after the recommendation was made, no formal response had been received from EASA or the FAA. [26] Rolls-Royce also acknowledged *'any oil leaking from an engine, entering the aircraft is classified as HAZARDOUS.'* [498] The Exxon Mobil MJO II MSDS (since 2004) acknowledges that the oil may decompose at elevated temperatures and produce *'harmful gases, vapours or fumes'* upon inhalation in a confined space leading to a variety of adverse effects. [267] The NYCO MSDS similarly states the product may decompose when heated and that *'Vapours or mist of heated product may be harmful by inhalation.'* [223] CASA advised that Mobil Jet Oil II was *'known to be harmful.'* [499] The German Government when asked if inhaling heated engine oil fumes is harmless to crew and passengers, it responded *'No.'* [368] A recent legal case stated '*Smoke from pyrolysed oil can be hazardous to the eyes, mucous membranes and lungs.'* [500] Clearly this is nothing new as the UK Government had 10 years earlier stated that inhaling oil mist would be hazardous and toxic. [501] It is now known that as far back as at least 1954, it was recognized that exposure to heated decomposition products from synthetic oil would be toxic. [146,147]

It is clearly for the reasons given above that numerous recognised authorities have recommended bleed air monitoring/detection systems and bleed air filtration or air cleaning technologies to be utilised so as to reduce the flight safety hazards. Such bodies include but are not limited to: RAAF/DSTO 1988; Australian Senate 2000; NRC 2002; ASHRAE 2007/2009; AAIB 2007/2009, US Senate & House of Reps.(2009); UK Parliament EDM 2008. [440,441] Interestingly SAE suggests that in order to meet bleed air contamination requirements (SAE ARP 4418) *'for aircraft such as military aircraft where the engine may have been designed prior to the design of the aircraft, it may be necessary to add filters to meet the above contamination requirements in the occupied compartments.'* [502]

In 2005 a Helios Airways B737 crashed killing all onboard. [462,503] While the cause was clearly attributed to the failure of the cabin to pressurise and the subsequent effects of hypoxia, the report and other data showed some findings of interest that cannot be excluded as possible contributory factors as to why the crews performance was effected so quickly. The accident report stated that 2 months earlier the aircraft technical log reported:

- *'Discrepancy; Unusual smell in cabin on ground with APU bleed supplying Packs... Maintenance action: Both LH-RH Packs suspected for oil contaminant. Turbofans suspected. APU as bleed source for two and* *half hours. Not possible to recall problem. Seems to be intermittent. Please Report Further.'*

While contaminated air was clearly not the primary cause, it should not be excluded as a possible contributory cause as there is a clear pattern of engineering failing to find the source of reported oil fumes with the request to please report further. [11,451] Interviews between the author and some crews who flew for Helios highlighted the common occurrence of oil fumes on their Boeing 737 aircraft. If contaminated air was present in the cockpit, the effects on the crew as the aircraft cabin altitude decreased would have been very significant. Fumes were reported on the Helios aircraft just prior to the inbound flight into Larnaca, in fact the second last flight the aircraft made, contaminated air was reported but was dismissed as *'galley fumes.'* Other reports of smoke/fumes related to the air conditioning were also reported. [504,505]

A clear sign that previous contaminated air exposures have occurred in an aircraft is by the presence of TCP (present in jet engine oils) on the interior surfaces of the aircraft. The majority of swab tests looking for the presence of TCP in commercial aircraft cabins (seen elsewhere in thesis) have to date been reported as positive. [320,506]

The statement by the ATSB in 1999 that oil smoke and fumes may constitute a *'possible safety deficiency'* is clearly incorrect. Oil smoke and fumes are quite clearly a serious flight safety issue and based upon action taken to date by the aviation industry to deal with the issue, it is a clear *'safety deficiency.'* This is because oil smoke or fumes clearly are to be '*reasonably regarded as having the potential to affect adversely the safety of aviation.'* [438]

2.7.8 To Summarise

The aviation industry has failed to treat this serious flight safety issue with the importance that it warrants. Any actions that the industry has taken to endorse and highlight the flight safety aspects of being exposed to contaminated air are rarely followed through and acted upon in reality. Procedures, written instructions and regulations mean little, if they are not followed through constantly with education, compliance monitoring and a real intent by the manufacturers, airlines and regulator to address the problem at all levels. The issue can only be properly addressed by using bleed free designs or fitting appropriate and effective bleed air filtration systems and detection systems to aircraft using *‘bleed air’*, along with the use of less toxic oils and better designed and maintained oil seals.

2.8 Inquiries, Conferences and Committees

2.8.1 National Research Council (NRC): The Airliner Cabin Environment - Air Quality and Safety, 1986

The 1986 NRC report acknowledged that oil seal leaks have sometimes permitted oil to leak into the bleed air and that little was known about the environment in the passenger cabins of commercial aircraft under routine flight conditions, and what was known was limited in scope. [507]

A number of conclusions and recommendations in the 1986 National Research Council (NRC) report related to contaminated air including the implementation of a data collection program that would measure airflow and contamination in airplane cabins. The introduction of a ban on smoking on all domestic flights and the establishment of a program for the systematic measurement, by unbiased independent groups, of the concentrations of carbon monoxide, respirable suspended particles on a representative sample of routine commercial flights was recommended as the NRC could not find any monitoring data on the concentrations of volatile organic chemicals in aircraft cabins during operation. The NRC also called on the Federal Aviation Administration (FAA) to establish a program to monitor selected health effects on airliner crews. Interestingly it was recognised that oil seal leaks could sometimes permit oil to leak into the compressor and then into the bleed air as a vapour or mist in extreme cases and that lubricants could be the source of VOCs. Additionally it was reported that *'contamination of the ventilation system (in military aircraft) by lubricating oil could lead to intoxication.'*

The most significant response the FAA took was to introduce a ban on smoking on most domestic flights in 1989. Apart from that only a limited number of one off studies were undertaken over the next twenty years which have contributed little to the resolution of the problem. [320]

2.8.2 Australian Senate Inquiry 1999-2000

The year long Australian Senate Inquiry began in September 1999 and produced a report officially known as the: Rural and Regional Affairs and

Transport Relations Committee Report on Air Safety and Cabin Air Quality in the BAe 146 Aircraft, Parliament of Australia, Canberra, October, 2000. [21]

The inquiry consisted of 9 hearings, 5 volumes of evidence from a large number of interested parties in addition to the final report. These included, but were not limited to: airline crews, airlines, British Aerospace, Union representatives, CASA, ATSB, and numerous other interested parties. The Senate Inquiry was effectively independent of government and made a number of conclusions, points and 8 recommendations to the government.

The Committee acknowledged that contamination of the cabin aircraft air, a persistent problem since at least the early 1990s, conflicted with at least three civil aviation regulations and was a defect which rendered the aircraft un-airworthy until the defect was remedied. The Committee expressed concerns that such defects may not be remedied immediately, modifications were only partially effective, and as a result, aircraft that were not completely airworthy continued to fly. The Chariman of the Senate inquiry recently advised that if the committee had been aware of all the data withheld by Ansett & BAe that has subsequently become available, he would have *'recommended that the BAe146 aircraft fleet be grounded until a solution could be found to safeguard the health and flight safety of the travelling public and aircrew.'* [508]

Additionally it was clearly recognised that the problem of contaminated bleed air occurred on other aircraft types in addition to the BAe 146. The committee acknowledged a clear link between crew health and air safety and that there was strong evidence of a tendency of pilots to under-report contaminated air incidents. It was also noted that exposure of aircrew and, potentially passengers to cabin air which may be contaminated or even minutely affected, by fumes originating in an aircraft's engines or APU raised the potential of an occupational illness which had left certain individuals with an incapacity to continue work. The Committee reported that it felt that the contaminated cabin air on the BAe 146 aircraft had led to short-term and medium-term health problems for a number of BAe 146 flight crew. (Medium term defined as up to 10 years) [509] It was also recognised that exposure to certain chemicals said to be not harmful were later found to have *'long-term deleterious affects'* and the committee could not accept assurances that there was no hazard associated with exposure to oil fumes in aircraft cabin air, particularly as British Aerospace advised there is a health issue associated with the fumes. [123]

The recommendations made included steps to protect the health and welfare of crews and passengers and included but were not limited to: [21]

- That the potentially hazardous chemical components of Mobil Jet Oil II be referred to NICNAS as a priority for review and assessment;
- Develop a standardised, compulsory monitoring program for testing cabin air during fume events;
- That the issue of cabin air quality be reviewed by the National Occupational Health and Safety Commission with a view to including aerotoxic syndrome in appropriate codes as a matter of reference for future Workers Compensation and other insurance cases;
- That CASA reassess its requirements for monitoring the operations and cabin and cockpit air quality of the BAe 146 aircraft operating in Australia;
- The National Health and Medical Research Council to set up and undertake an appropriate research program on the effect of exposure to aircraft cabin air on aircrew and passengers;
- Appoint an experienced, retired judicial officer or eminent person who is appropriately qualified to conduct a review of unsuccessful or inordinately delayed employees' compensation cases, pilots' loss of license insurance, personal income protection, and with-held superannuation/other insurance claims made for personal injury and loss of employment as a result of ill health claimed to result from exposure to fumes on the BAe 146 and other aircraft… to determine if dealt with according to requirements and appropriate standards of procedural fairness;
- CASA assess how quickly fitting appropriate high-grade air filters can be made mandatory for all commercial airliners flying in Australia to minimise any deleterious health effects arising from poor aircraft cabin air on crew and passengers.

The Government set up a references committee to deal with the recommendations, however apart from the issuing of 2 Airworthiness Directives for the BAe 146, none of the other recommendations were acted upon. [510] In 2006 Senator O'Brien was advised by CASA that the references committee had met twice in four years and it was clear that CASA had little knowledge of the committee that it chaired. [511]

In 2008 CASA established a new independent Expert Panel on Aircraft Air Quality discussed later in this chapter.

2.8.3 UK House of Lords Inquiry, 2000

In 2000 the UK *'House of Lords Inquiry'* took place and was officially called the House of Lords Select Committee on Science and Technology - Air Travel and Health. [2] While the Australian Senate Inquiry very specifically took over one year to investigate air contamination on aircraft only, the House of Lords Inquiry called for evidence shortly after the majority of the Australian inquiry was completed in May 2000. The UK inquiry however looked at a very wide selection of issues ranging from Deep Vein Thrombosis, transmission of infection to seating and medical emergencies. As a consequence of the broad remit it was unable to investigate contaminated air issues anywhere near as extensively as the Australian Senate Inquiry had previously. Oral evidence to support written submissions was limited to Government and aerospace industry bodies taking place over six weeks and excluded crew unions or medical/scientific experts who had seen crew or published papers.

The House of Lords dismissed cabin air contamination from oil leakage as a concern but placed great emphasis on the general issue of passenger's poor perception of cabin air quality. It called for research so as to refute the *'common allegations'* and give public confidence regarding aircraft air quality. A number of recommendations on air quality were provided to the Government, which included the recommendation that airlines carry out simple and inexpensive cabin atmosphere sampling programmes from time to time, and to make provision for spot-sample collection in the case of unusual circumstances. The report also called for basic cabin air data to be monitored on a continuous basis and for regulators to extend the forthcoming ASHRAE air quality standard beyond just CO, CO_2 and O_3. Finally the Government was recommended to commission research on the highest priority basis into the real time monitoring of air quality and other aspects of the cabin environment, with a view to establishing new and clear regulatory minima for passenger cabin ventilation.

The standard of analysis of the oil contamination issue was very poor with emphasis placed on industry and Government bodies, which had no direct experience in the actual problem. The factually flawed statement in the final report referring to TCP exposure has been quoted by the UK Government and airline industry over many years: [2]

- *'The absence of confirmed cases of tri-ortho-cresyl phosphate (TOCP) poisoning from cabin air and the very low levels of TOCP that would be found in even in the highly unlikely worst case of contamination from oil leaking into the air supply lead us to conclude that the concerns about significant risk to the health of airline passengers and crew are not substantiated.' (1.72, 4.41)*

This statement was made based on the evidence of the oil, engine and aircraft manufacturers as well as evidence presented by Dr Virginia Murray of the UK Medical Toxicology Unit. Dr Murray stated '*no case data has been found about any enquiry relating to exposure to TCP',* that the only data found related to literature searches and that she was *'not convinced that the data is being collected.'* [512] The reference in the final report to TOCP and evidence given almost entirely focussing on TOCP alone, ignores the fact that it is the oil that was presented as the problem with TCP being made up of 10 isomers of which the more toxic ortho isomers were known about since 1958 and in the oil at far higher levels. This was completely ignored, despite clearly being raised directly with the inquiry and previously clearly highlighted at the Australian Senate Inquiry by Mobil in its various written submissions. The evidence given by crew organisations, crews and experts with direct experience with crew effects related to fume events, was almost entirely ignored. The BALPA evidence given to the inquiry included key comments like *'progress appears to be slow or non existent'* and that the issue should be treated with the *'appropriate urgency',* comments which are still valid today. [513] As of 2009 airlines had not yet introduced spot-sample collection procedures during the case of unusual circumstances.

2.8.4 UNSW/ADFA Aviation Air Quality Conference: December 2000

The University of New South Wales (UNSW), School of Safety Science and The Australian Defence Force Academy (ADFA), held an Aviation Air Quality Symposium at the Australian Defence Force Academy in Canberra, Australia, on 7 December 2000 following the release of the Australian Senate Inquiry report two months earlier. The conference covered a wide variety of topics specifically related to leaking oil fumes ranging from regulatory, engineering and operational aspects to occupational health and published a strong consensus statement. [514] The statement supported and urged the Government to enact the Senate Inquiry recommendations in full and deplored the absence of the regulator to attend as it (CASA) did not consider fumes to be an imminent threat to safety. It suggested reporting procedures for oil fume events should be enforced more broadly than under current regulations and that oil fumes ought to be seen as a *'major defect'* and an airworthiness issue as specified under current regulations, necessitating the aircraft to be grounded until the defect was fixed.

2.8.5 National Research Council: The Airliner Cabin Environment and the Health of Passengers and Crew, December, 2001

Largely as a follow up to the recommendations of the 1986 NRC report, coupled with growing public, crewmember, union concern over problems with aircraft air quality and most likely the recent release of the Australian and UK Government Inquiries, the US Congress took further action in 2000. Congress directed the FAA in the Wendell H. Ford Aviation Investment and Reform Act of the 21st Century (PL106-181), enacted in 2000, to request the NRC to perform another independent review of cabin air quality and the health of passengers and crew. The NRC convened a new committee which released their 246-page report titled *'The Airliner Cabin Environment and the Health of Passengers and Crew'* published by the National Research Council in January 2002. [25] The committee was charged with investigating all facets of cabin and flight deck air including the ways in which contaminants might enter the cabin and flight deck air supply systems and any toxic effects associated with such exposures.

The committee was also asked to address measurements of the contaminants of concern in the air of passenger cabins during domestic and foreign air transportation and comparison with measurements in public buildings, including airports. Additionally the committee was asked to investigate potential approaches to improve cabin air quality, such as an alternative air supply for the aircraft passengers and crew to replace the air supplied through the engines.

The committee appears not to have taken evidence from independent medical doctors or from any crew member unions except for the US Association of Flight Attendants, AFL-CIO (AFA) in the US.

The 2002 NRC report [25] concluded that contaminant exposures from engine lubricating oils, hydraulic fluids, de-icing fluids, and their degradation products do occur under routine operating conditions and under abnormal operating conditions and can leak into the cabin into the aircraft cabin. Furthermore, the report stated that there were no published studies that describe quantitative measurements of air quality under abnormal operating conditions and that laboratory studies were suggesting that many compounds (volatile and non volatile agents including TCP) are released when the fluids are heated to high temperatures into the bleed air system. Consequently the report recommended that Congress appoint a lead federal agency and provide sufficient funding to establish a research program to help answer a number of high priority questions including: What is the toxicity of the constituents or degradation products of engine lubricating oils, hydraulic fluids, and deicing fluids and to investigate if there is a relationship between exposures to the chemicals and reported health effects in cabin crew and how these oils and fluids are distributed from the engines into cabin environment. Additionally, they recommended that the potential synergistic and interactive effects of exposure in the aircraft cabin to reduced barometric pressure, low humidity, O_3, other chemical contaminants, and pesticides also be examined.

The report made the link that air contaminants can be responsible for some of the numerous complaints of acute and chronic health effects in cabin crew and passengers; and that the oil, fluids and their potential degradation products if released into the cabin air supply will adversely affect cabin air quality. However, the report stated that available health data had not been collected in a standardised, systematic manner and therefore, establishing a causal relationship between cabin air quality and the health of cabin crew and passengers was extremely difficult. Therefore the report made the recommendation that a program for the systematic collection analysis and reporting of health data in relation to cabin air quality needs be implemented to resolve many of the issues raised in their report.

The report recommended that there be a rigorous review and revision of the FAR standard related to cabin air quality if the FAR was found to be inadequate to protect the health and comfort of passengers and crew. A significant recommendation made to the FAA was that they investigate and publicly report on the need for and feasibility of installing air-cleaning equipment for removing particles and vapors from the air supplied by the ECS on all aircraft to prevent or minimise the introduction of contaminants into the passenger cabin during ground operation, normal flight, and under abnormal operating conditions.

Two other key recommendations made in the NRC report were that the FAA should require a CO monitor (routine surveillance) in the air-supply ducts to aircraft cabins as CO was deemed to be most likely produced, during engine oil and hydraulic fluid leaks. Secondly, wipe samples of aircraft cabin, cockpit, and ventilation ducts should be taken and analyzed after air quality incidents to identify the contaminants to which passengers and crews were exposed and that filters from the aircraft ventilation system be analyzed to identify contaminants that have collected on them.

The report was particularly critical over the FAA's inaction regarding the implementing the recommendations of the 1986 NRC report. Two examples involve the 1986 recommendation to establish a *'program to monitor health effects of cabin crew*' and the call to '*implement a data-collection program that measures airflow and contamination in aircraft cabins.'* The former was never undertaken and the later was interpreted by the FAA as a single study (not an ongoing initiative) by the Department of Transportation in 1987 which assessed cabin air quality on 92 flights without any air supply contamination incidents. [515] The 2001 NRC committee found it *'regrettable'* that the FAA had interpreted the requirement to carry out a '*program*' as a single study as the *'1986 committee's clear intent was to establish continuing monitoring and surveillance.'*

The NRC report advised against the use of the term *'aerotoxic syndrome'* related to exposure to leaks of engine oil or hydraulic fluid as it considered there was insufficient evidence to link the symptoms to the exposures. However the non standard use of terminology used to describe symptoms in the various surveys reviewing crew health to date, should be reviewed closely for the commonality of adverse effects. [398] Many of the reported effects, despite being recorded with no air monitoring at the time, are well documented via the standard industry reporting formats showing fume events were accepted as occurring or leaks were identified.

During the time that the NRC committee was conducting its year-long aircraft air quality review (2001), an FAA-sponsored working group was busy developing the scope of an air quality rulemaking task for which an industry-dominated Aviation Rulemaking Advisory Committee (ARAC) group would be tasked to develop proposed language. Shortly after the scope of the proposed rulemaking was finalised, 9/11 happened, and the sole focus of the FAA and airlines became aviation security while the primary focus of US crewmembers became job security.

In February 2002 the FAA issued a response to the NRC report. [516] The report found that the FAA generally concurred with the intent of the NRC recommendations. [516] An implementation schedule was published by the FAA, showing the various bodies to be charged with implementation. [517] These included the FAA and DOT, an FAA ARAC committee and ASHRAE. The FAA surprisingly posted on it's website a final report [516] along with separate segments [517] that made up the final report. However there are number of key differences between the final report and the individual components that supposedly contributed to the final report, in effect 2 versions: the individual components making up it's response to the NRC report on it's website, one which acknowledges it's failure to regulate air quality [517] and the final report which is more forgiving. [516] For example, in the final report version, the existing design standards were seen to provide adequate air quality during normal operations, but it was accepted that *'FAA rulemaking may not have kept pace with public expectation and concern about air quality and does not afford explicit protection from particulate matter and other chemical and biological hazards.'* [516] However in the individual component version, the FAA additionally stated that '*No present airplane design fulfils the intent of 25.831 because no airplane design incorporates an air contaminant monitoring system to ensure that the air provided to the occupants is free of hazardous contaminants.'* [18,517] Clearly this is due to the fact that all modern transport aircraft use bleed air. This key statement is a critical exclusion in the final ACERRT report. This version of the report also noted that industry had expressed agreement that filtration mechanisms and a monitoring system recommended by the NRC are part of the requirements to ensure compliance. [517] Also of note is that the FAA sought to adopt air quality standards developed for ground-based industrial environments for use on commercial airplanes, although many parties consider these standards unsuitable and outdated.

In addition to the FAA tasking ARAC to review the standards it was also required to address their concern over the discrepancies in reporting fume events. The FAA report [516] advised that it did not think that *'a continuously operated air quality monitoring system will add significant benefit for passengers and crew, especially relative to the added cost.'* This was partly due to it's own internal review that found air quality events impacting on cabin air quality as '*highly improbable'* estimated as occuring between 10^{-5} and 10^{-7}, yet with the recognition that not all events may be reported as there was *'no requirement for crewmembers to report air quality events.'* [516] However air contaminant identification and isolation procedures would be reviewed by the FAA rulemaking activities. The FAA response to the NRC recommendation on CO monitoring resulted in the FAA stating again that no aircraft currently met airworthiness regulation 25.831 as there were no monitoring systems to ensure the air was free of hazardous contaminants. It also stated that instead of monitoring for CO, it was other chemicals, gases and particulate material that should be monitored.

With regard to the air monitoring and concurrent health survey recommendation, the FAA noted that *'Combined government, industry, and union participation will be critical to the success for the effort',* noted the difficulties in undertaking such research, suggested health surveys were *'subjective'* and noted '*industry legal and operational concerns could affect the effort.'* The recommendation that research be led by the FAA was sure to be fulfilled when the FAA proposed to couple research needs related to biological and chemical terrorism on board aircraft with those related to unintentional air contamination events. This would not only deal with the air contamination issue but would support the Transport Security Agency (TSA) biological and biochemical attack concerns of the aviation industry and the flying public. The FAA recommended that the air monitoring/health survey and research questions be addressed through a research project that operated under the auspices of, and partly funded by ASHRAE, with a small FAA contribution, but designed, championed and largely funded by Boeing. However the scope of that research project clearly states that it was *'not intended to address upset conditions'* (fume events). [3,518] Therefore, it was disingenuous to suggest that FAA's contribution to the study satisfied any air monitoring for the smoke/fume events that the NRC committee had raised as a concern. Additionally the FAA's contribution in no way satisfied the NRC report recommendation for continuous monitoring of the bleed air system with flight deck indication and crew training.

As of 2009 the NRC recommendations to justify/revise the FAA regulations on aircraft air quality, research the oils and hydraulic fluids, require bleed air monitoring and investigate air cleaning technologies have not occurred. Eighteen months after the NRC committee report was published, the US Congress passed legislation (Public Law 108-176, S 815) directing the FAA to fund research into specific cabin air issues. With one exception, the FAA did not solicit research proposals in a competitive bidding system. Instead, members of the Airliner Cabin Environment Research (ACER) consortium received most of the funding. For the oil smoke/fumes related research, the FAA co-funded the Occupational Health Research Consortium in Aviation (OHRCA) and ACER with a two-year grant. After two years, the research team had been unable to secure a single airline partner that would allow its flight attendants to carry a small, portable air sampler onboard without fear of discipline. This necessitated a change in the research design. Researchers carried and exposed the air samplers themselves on commercial flights. Of 55 samples analyzed, 10 (18%) tested positive for at least one TCP isomer, all on flights without visible smoke/fumes and without the person collecting the samples reporting any symptoms. [3,519,520] The final report also described the results of a comprehensive flight attendant health survey that could not attribute symptoms to air quality, specifically, but identified a high rate of self-reported neurological and respiratory complaints, worthy of additional investigation. [519,521] Finally, the report included a health care provider's guide intended to educate physicians about the potential for exposure to oil fumes and the associated symptoms. [519,522]

The AFA was very critical of the FAA response to the NRC report, particularly noting the agency's heavy reliance placed upon the industry dominated ARAC committee which did not appear to include suitable industrial hygiene or medical expertise. [523] The AFA expressed concerns of the FAA reliance upon clearly recognised flawed data in the frequency and therefore seriousness of contaminated air events. Additionally the postponement of ARAC review until the Boeing/ASHRAE/Battelle study was completed supposedly in early 2007, was deemed inappropriate as was the failure to monitor CO. This study has now been extended to cover the ACER/FAA and ASHRAE/Battelle research, which is still ongoing as of 2010. The study appears to be coverd by the *'In-flight Measurements of Cabin Air Quality'*, a currently ongoing joint Harvard School of Public Health (FAA-funded) Battelle Laboratories (ASHRAE-funded) research project. [524] '*The objective of the project is to understand the relationships among environmental conditions of the cabin (as well as other factors) and the perceptions of health and comfort of passenger and crew members.'* The *'anticipated Outcome'* is the *'assessment of overall cabin air quality of aircraft during normal operation.'* [524]

2.8.6 BRE Conference 2003

In October 2003 Building Research Establishment Limited (BRE) organised a two day industry conference at the Royal Aeronautical Association in London to discuss the cabin environment. [525] Some of the conference was related to contaminated air.

The presentations given covered predominantly cabin air quality and cabin air systems in normal conditions, future designs of cabin air systems, passenger comfort and health, the proposed ASHRAE research and standard (commenced in 1997) and the European research and pre-standard on air quality. Additionally the impact of bleed air on engines, the cost benefit analysis in relation to air quality, considerations for prevention or treatment of bleed air contamination, potential monitoring or removal systems and filtration systems were discussed. Transmission of infectious diseases was also considered, yet no occupational health and safety or health effects directly related to cabin air contamination were addressed, apart from a BRE presentation that effectively stated irritant effects only *'are potentially possible*' as doses high enough to cause more severe problems were '*very unlikely*'. [526] No independent scientific or medical doctor or crew representative body was asked to present a paper.

The CAA advised that operating crews experiencing headaches, upper airway irritation or nausea was not their concern, as it was not seen as part of their *'safety focus'*. [124] When referring to the airworthiness ventilation regulation 25.831a, the CAA presentation acknowledged that the passenger and crew compartments must be ventilated, however failed to mention that each compartment '*must have enough fresh air… to enable crewmembers to perform their duties without undue discomfort or fatigue.'* [124] The overall tone was that contaminated air really wasn't anything to worry about. This was in complete contrast to the views given by the NRC and the Australian Senate and was in marked contrast to recent new data emerging from CAA FODCOMS, Airworthiness Directives (ADs) and BAe All Operator Messages (AOMs) all expressing that contaminated air was a safety of flight issue. However none of these regulator or manufacturer initiatives were mentioned.

Rolls Royce acknowledged when referring to the impact on aircraft safety assessment that '*any oil leaking from an engine, entering the aircraft customer bleed offtake is classified as HAZARDOUS.*' [498] Additionally Rolls Royce focussed on more reliable sealing of bearing chambers, particularly during transient engine manoeuvres. It was clearly recognised that there were a number of options available to monitor, reduce and treat air contaminants entering the air supply system, however Honeywell acknowledged it was not possible to prevent contaminants but necessary to treat where *'feasible'.* [525]

The conference did not move any closer to establishing real research to address the problem and was clearly established to continue ignoring real data from the field with a clear industry bias shown.

2.8.7 BALPA Contaminated Air Protection Conference: 20-21 April, 2005

British Airline Pilots Association (BALPA) were aware that many crews had and continued to suffer short term symptoms from exposure to contaminated air such as headaches, nausea, fatigue, eye-nose and throat irritation, etc. They also knew that some crew members had been incapacitated and that some of their members or their doctors believed that their long-term health had been affected from exposure to contaminated air. As CAQTG chairman, Captain Tristan Loraine decided that a conference was much needed and therefore secured conference sponsorship from those who had solutions. Shortly afterwards, aware of the increasing evidence of a problem, two UK MPs, Paul Tyler and John Smith publicly called for the conference to take place.

The objective of the conference was to raise industry awareness of likely contaminated cabin air issues, to address available monitoring techniques and to offer potential solutions in the event that a problem was identified. Every major airline, aircraft manufacturer, lubricant supplier, regulator as well as all interested medical and scientific doctors and researchers were invited to present a paper at the two day conference. Everyone who wished to present a paper was accommodated. No airline, manufacturer or regulator asked to give a presentation.

The conference saw many of the world's leading independent experts in chemical exposure effects attending and presenting data which clearly left attendees in no doubt that the airline industry had a problem. [527] The Conference also clearly showed that if there was a will to do so that technical solutions existed to help significantly remove a lot of the contamination by way of filtration techniques, which were reported to be relatively inexpensive.

The published conference closing statement signed by all independent experts stated: [527]

1. There is a workplace problem resulting in chronic and acute illness amongst flight crew (pilots and cabin crew);
2. The workplace in which these illnesses are being induced is the aircraft cabin environment;
3. This is resulting in significant flight safety issues, in addition to unacceptable flight crew personnel health implications;
4. Passengers may also be suffering from similar symptoms to those exhibited by flight crew

Government, industry and regulators were called on to urgently work with cabin environment, medical and analytical specialists, crew representative bodies to address the problems identified. To date, this still has not effectively taken place.

2.8.8 Committee of Toxicity: The Cabin Air Environment, Ill-Health In Aircraft Crews And The Possible Relationship To Smoke/Fume Events In Aircraft, 2007

In September 2004 the British Airline Pilots Association (BALPA) wrote a six page letter to the UK COT or the 'Committee On Toxicity of Chemicals in Food Consumer Products and The Environment (COT)' outlining their concerns in relation to contaminated air and seeking an independent investigation, [70] but to no avail. [528,529]

BALPA then sought to attract UK airline support for the completely independent US multi million dollar Occupational Health Research Consortium in Aviation (OHRCA) research project. UK airlines indicated that any participation would only be given if the CAA endorsed the OHRCA research. BALPA approached the airline funded CAA who indicated any such research would need the endorsement of the Department for Transport (DfT), they in turn indicated the matter needed the endorsement of UK Aircraft Health Working Group (AHWG) and the UK AHWG in turn asked the UK AHWG Research Sub Group (RSG) for a view. Whilst the AHWG RSG was investigating the question of UK airline participation in the OHRCA project and with increasing pressure being brought on the UK Government by BALPA, the TGWU, the IPA and other interested parties, in March 2005, BALPA were asked by the AHWG RSG chairman, Dr William Maton-Howarth, Chief Research Officer for Public Health, Department of Health (DH), to provide evidence to support its view that crews were getting sick and that a flight safety problem existed. The DfT then requested that the DH undertake a scientific review of data submitted by BALPA. The Health Protection Agency (HPA) COT secretariat and the DH Toxicology Unit, Imperial College were commissioned by the DH to review the BALPA submission and prepare a discussion paper for the COT.

The Government decision to request the COT to investigate matters was done so knowing that the US OHRCA project was only funded till mid 2007 and that the COT report would not be completed until 2007.

When BALPA and the TGWU became aware that the review of their evidence was going to be done by the COT committee, they immediately raised their strong concerns with the Government about the lack of transparency under which the committee would operate. They also made numerous requests to ensure that the committee would receive public input, use independent expertise and that the whole process would be open for public scrutiny. [530]

None of the BALPA or TGWU requests were met and the COT was appointed to review the BALPA data without BALPA or the TGWU being able to appoint independent experts to the committee.

It took a year for the COT secretariat to prepare a discussion paper, which was released in June 2006. [531] This was longer than was suggested at the July 2005 AHWG RSG. [532]

The discussion paper was immediately heavily critiqued by many, including the Australian based non-profit group, AOPIS. It raised concerns that the COT secretariat lacked expertise and understanding of many of the issues relating to the contaminated air debate. AOPIS wrote to Professor Ian Rowland the COT Chairman, which included the statement: [533]

- *'We have carefully studied this information and now believe the COT Secretariat has systematically misrepresented factual information thereby potentially misleading not only members of the main COT Committee but all readers of their report (TOX/2006/21), including the public. This theme of misrepresentation of data also applies to the Annexes prepared by the COT Secretariat.'*

AOPIS also sent UK Government officials including the Secretary of State for Health and the COT Secretariat an 18 page report listing numerous errors and misrepresentations. The report listed many concerns covering all areas of the report. [534] As an example the work of Australian psychologist Leonie Coxon was clearly misrepresented as the COT report stated her work found subtle changes in cognitive performance. The Coxon published paper in fact found *'mild to moderate/severe and severe/significant impairment'* in the aircrew tested. [402] Dr Coxon wrote directly to the COT Chairman to advise him that she had been *'misrepresented'* in the COT draft report. [535] The COT interpretation of the UK Contaminated Air Database [536] severely downplayed the hazards identified through the reported incidents and inappropriately accepted the CAA under-reporting of actual reported contaminated air events. Additionally the COT report stated there was no evidence of TCP in the cabin air, however failed to take into account all of the swab sampling that had been advised to the committee identifying TCP in filters and on aircraft cabin surfaces, TCP identified in previous RAAF studies, Ansett and Swedish /Allied Signal studies and elsewhere. [320]

AOPIS concerns with the COT draft paper were echoed in over twenty other letters written to the COT chairman highlighting serious concerns about their discussion paper and the way the COT were undertaking their investigations. Letters came from individuals, doctors, scientists as well as unions such as the TGWU, BALPA, Teamsters Canada, AFA, IPF and the IPA.

The Independent Pilot's Federation in the UK stated that [537] the Federation is *'concerned that the misrepresentations and misinterpretations of the evidence put forward in the Discussion Paper are deliberate and designed to minimise and mitigate the changes required to achieve closure of the Cabin Air Contamination problem... It would appear that the Government and CAA give* *scant regard for the health and well being of Flight Crews or the travelling public and obviously feel they have no Duty of Care to either group... It is time the various Government departments stop defending their positions, accept there would appear to be a problem, thoroughly investigate it and come up with some solutions... How many more crew members have to lose their medical licences and hence jobs?'*

In early 2007, AOPIS again complained to the UK Government and to the COT Committee about the way the COT Secretariat were dealing with their contaminated air investigations. This was done by way of a 20 page report which primarily dealt with the second draft COT discussion paper, TOX/2006/39. [538] In addition to questioning the committees lack of relevant clinical expertise, one of the many major concerns was the uncritical acceptance by the COT committee that the British Airways figures showing that oil fume events were reported in 1% of flights and were identified by engineers in 0.05% of flights, roughly supported by 2 other UK operators, was a true indication of the frequency of events. This completely failed to take into account the well-acknowledged problem of under-reporting. Another example of the selective use of information related to the latest COT discussion paper involving the statement that discussions had been initiated with Dr Peter Julu about his findings, when no more than an initial email to find suitable dates for a meeting was ever undertaken. Just one more of the many incorrect statements was the COT acceptance that oil fumes do not need to be reported in the aircraft technical log as indicated by the CAA and a statement obtained under FOI, [539] given and accepted uncritically by the COT committee by a BALPA representative. This statement indicated that there is no requirement to report such fumes and most of the fumes are related to toilet odours or galley smells. This is contrary to the BALPA evidence actually submitted to the committee. However, it was accepted by the secretariat and was given full endorsement in the report TOX/2006/39.

COT meetings did not allow any audio or visual recording of the meeting. The minutes of the meetings repeatedly provided information in an inaccurate manner. The minutes failed to record for instance that Professor Furlong's advised the COT committee that their focus on OPIDN or neuropathy as an end point for effects of exposure to organophosphates was misguided and they were looking at the wrong *'end point of exposure.'* As just one more example of a medical expert's concern, Dr Andrew Harper notified the COT Chairman that it's position *'fails to define the severity and seriousness of the medical an*d p*ublic health problem… the COT has deferred to Science for arbitration over the nature and importance of the problem.'* [540] A further letter from Dr Harper stated that the approach being with an emphasis on the *'quest for scientific validation… could effectively delay and postpone preventive and protective intervention indefinitely. This is because environment exposure studies are insensitive and can be totally negative despite the existence of a significant Public Health problem.'* [541]

The independence of the COT committee has been questioned by many. These include the media, doctors, scientists, trade unions, researchers, crew members as well as Lords and members of parliament. [542,543]

In September 2007, the COT committee released its final report stating repeatedly *'there was insufficient evidence'* and included the following comments: [70]

- 69. …the calculated incidence of oil/hydraulic fluid fume contamination was approximately 1% from pilot reports and approximately 0.05% following engineering investigation;
- 85. ...it would be prudent to take appropriate action to prevent oil or hydraulic fluid smoke/fume contamination incidents;
- 86. It was not possible on the basis of the available evidence in the BALPA submission or that sourced by the Secretariat and DH Toxicology Unit to conclude that there is a causal association between cabin air exposures (either general or following incidents) and ill-health in commercial aircraft crews. However, we noted a number of oil/hydraulic fluid smoke/fume contamination incidents where the temporal relationship between reports of exposure and acute health symptoms provided evidence that an association was plausible;
- 87. There was considerable uncertainty regarding the identity of VOCs, SVOCs and other pyrolysis products released into the cabin air during an

oil/hydraulic fluid smoke/fume incidents... Approaches to exposure measurement should address the widest possible range of potential contaminants from oil/hydraulic fluid that could be analysed and should not focus on only a single chemical group or compound;

- Overall, there was insufficient evidence available to the COT to recommend additional epidemiological research on any acute health effects;
- There was insufficient evidence to justify epidemiological research focusing specifically on OPs;
- The available evidence, although limited, together with information from pilots, supported further investigation of neuropsychological impairment in commercial pilots... However, there was insufficient evidence to recommend any specific additional research for any other acute or chronic health effect with regard to oil/hydraulic fluid contamination incidents on commercial aircraft.

In May 2008, an eleven-page critique report on the COT investigation and its report was prepared for the AFA. [544] The critique outlined how the COT Secretariat had misled the COT committee, misrepresented the scientific findings of many doctors and scientists and made the following conclusion:

- *'This critique of the 2007 COT review on the suggested relationship between pilot ill health and exposure to oil fumes found many errors and misleading statements, as described. We call on UK regulators and researchers who may rely on the COT findings to reconsider the facts as outlined here and to proceed with a carefully designed sampling strategy that is honestly intended to assess the health impact of exposure to oil fumes.*

The conclusion was in fact what the US OHRCA project had intended to do and what the UK Government prevented from happening and which would have been of no cost to the UK taxpayer.

Subsequent to the release of the COT report the UK DfT commissioned monitoring research to be undertaken via Cranfield University which is ongoing over three years later and in many people's opinion is equally as flawed at the original COT report. [342,545]

Effectively, the COT report incorrectly established that there was insufficient data available on the health effects and no data to indicate what might be causing the contaminated air. As such, given that no monitoring has been undertaken at the time of the adverse effects and therefore no causal relationship could be drawn, it would not be possible to conclude if there was a temporal relationship until these 2 events were undertaken simultaneously. All other data has been effectively ignored. Therefore the Government chose to commence the Cranfield monitoring studies, as many see it, in order to determine if levels found could be responsible for adverse health effects and then determine if additional research on adverse health is ever required. The ill informed COT position was summarised by a committee member at an industry conference in late 2008 when referencing TOCP alone and OPIDN only. [546] The reference to TOCP alone and OPIDN ignoring all other isomers and evidence despite it being known since 1958 that this was inappropriate summed up the relevance to the debate. This also ignored health issues that are generated well before OPIDN could be observed.

2.8.9 House of Lords 2007

In 2007, the UK House of Lords chose to update its previous 2000 report on Air Travel and Health. [547] Once again the report looked at many aspects of the issue rather than purely air quality. However, it was accepted that oils and hydraulic fluids can enter the cabin air after being subjected to extreme temperatures causing thermal decomposition (pyrolysis) into a range of substances such as *'volatile organic compounds (VOCs), low molecular weight organic acids, esters, ketones and tri-cresyl phosphate isomers.'* The report made four recommendations including: the CAA carries out an awareness campaign aimed at airlines and pilots to highlight the importance of reporting contaminated air events; AHWG sponsored research into contaminated air substances be completed *'urgently'*, followed by an epidemiological study on pilots to ascertain the incidence and prevalence of ill health in aircrew and any association there might be with exposure to the chemicals identified in the AHWG-sponsored study, paying particular attention to the synergistic effect of these chemicals; Government works with manufacturers, airlines and the regulator to take effective action in preventing oil and hydraulic fluid leakages into the aircraft cabin; protocol should be made available to health professionals, authorised medical examiners, on how to deal with aircrew who suffer contaminated air events and airlines, the regulators and the Government work together to improve the support given to pilots claiming to suffer ill health following a contaminated air event.

To date, three years later, none of the recommendations have been adopted by the British Government apart from the heavily criticised Government sponsored research into substances found in the air being undertaken on an ongoing basis to date by Cranfield University. [342,545,548] While the inquiry made some key findings, it is clear that the committee clearly did not have the expertise to deal with the contaminated air issue. One such example is the House of Lords committee comment that the GCAQE claimed that with regard to TCP, TOCP was the least toxic of the ortho isomers with MOCP and DOCP being 10 and 5 times more toxic respectively, however the committee stated it had no confirmation of this one way or the other. This information has been published since 1958 (Henschler) and was identified by Mobil in their 1999 paper as well as being listed in many other published papers including the Aviation Contaminated Air reference Manual which the House of Lords declined to review. The formal Government response apart from the Cranfield monitoring studies was effectively dismissive stating [549] that reporting systems were all in place and working; health impacts could not be assessed until the monitoring had been completed; it would work internally with its chosen stakeholders in the AHWG and the Society of British Aerospace Companies (SBAC) representing manufacturers; a medical protocol could not be established until the substances in the Cranfield monitoring were identified with links to crew ill health. However, the AHWG had determined it was not possible to devise a *'genuinely useful protocol at this stage of the debate.'*

2.8.10 Australian Expert Panel on Aircraft Air Quality (2008-2010)

In September 2008 the Australian aviation regulator CASA announced that it had established an independent Expert Panel on Aircraft Air Quality (EPAAQ). The panel was to have a broad mandate covering both safety and occupational health and safety matters. The committee would take 18 months or so to review the evidence delivering its findings and recommendations in the first quarter of 2010. The panel Chairman, Dr Michael Bollen, a Medical professional has wide-ranging experience in chairing successful committees, often with diverse memberships. [550] The panel includes medical experts ranging from those with no aviation experience, the CASA Senior Medical Officer, head of medical research for the Royal Australian Air force and one Doctor having sat on an airline selected panel on the issue in the 1990s. The panel also included representatives with toxicological experience unrelated to the contaminated air issue and pilot and engineering union representatives. In order to prepare its report, the expert panel will review existing literature on cabin air quality and seek submissions from interested parties. The GCAQE was the initial organisation that was asked to give a presentation to the EPAAQ in November 2008, which was carried out by the author.

2.8.11 Additional conferences

There have been a number of additional conferences over the years, some which have been seen as proactively looking at the latest available data, while most have been organised by the aviation industry with the similar presentations given year after year, almost entirely ignoring the actual evidence available on the contaminated air issue with regards to flight safety, airworthiness and the OHS issues being recorded. Some of the key conferences are listed below.

In 2007 the GCAQE was denied permission to give a presentation on the contaminated air issue at the IATA aviation health conference, the main global aviation health conference. The GCAQE was advised *'This annual conference assembles medical specialists and inflight management interested in cabin health issues. All speakers whishing to present at the conference must submit an abstract for review prior to being accepted as speakers. This is to ensure relevance of the topic for the audience, credibility of the sources, conclusions based on scientific information and a non-commercial approach'.* [551] The following year the application was accepted with the author invited to give a presentation on behalf of the GCAQE. [552] However, the conference again showed an exceptionally heavy bias with seven out of the eight air quality presentations given by representatives from aviation regulators, Government/industry research, manufacturers and airlines. Once again, independent medical and scientific experts were not invited to present their findings and the emerging trends related to crews and passengers inhaling synthetic oil lubricants in flight were not discussed apart from the GCAQE presentation. Instead the presentations focussed on cabin air systems and identifying contaminated air substances so as to determine if sufficient levels could be responsible for reported concerns. Overall the approach was dismissive with the global independent evidence ignored.

In 2009, the European led Ideal Cabin Environment (ICE) conference [553] was held in Germany with an almost identical approach and the same limitations seen in the previous industry conferences. The objective of the ICE program is to provide manufacturers and airlines with information about the unknown combined effects of a select number of cabin environment parameters on the health of passengers. A number of new areas were included in the research such as the synergistic effects of cabin environment parameters, cabin pressure and hypoxia and possible links with DVT, however contaminated air related to oil and hydraulic fluid leakage was not part of the focus of the European research. Despite the fact that contaminated air was not part of the research as bleed air was not a parameter examined during the research, numerous presentations concluded cabin air was not a problem for crew or passengers. The European preStandard (EN 4618, Pr EN 4666) for aeronautical air quality failed to include contaminated air as a part of it's focus, while the ICAO Chief medical Officer when discussing ICAO activities on passenger and crew health did not even mention contaminated air as an ICAO area of activity.

Other conferences have covered the broad issue of cabin air quality, but have focussed almost no attention on the occupational health and safety and flight safety aspects of the contaminated air issue. [554,555] Other conferences rejected the GCAQE application to give a presentation on the contaminated air issue. [556,557] The US FAA funded OHRCA research group, specifically researching aspects of contaminated air, was requested to participate in a panel/presentation at the Aerospace Medical Association 2008 conference. The application was rejected as it was stated that *'The FAA should not be* *referenced and an FAA disclaimer should be included in any paper which must be reviewed by the FAA. Blood test and portable cabin air monitoring are methodologies that are not yet published nor adequately validated. Symptoms reported are subjective with no statistical evidence provided as support. There are no methods defined to support the results and conclusions reported. Results are not based on any presented data'*. [558]

Other conferences that have willingly requested that the cabin air issue be highlighted include the 2007 Royal Aeronautical Society conference on Smoke, fire and fumes in the cockpit, and the 2007 Flight International Crew Management Conference in Brussels. In fact presentations were given on the research undertaken by the author and the GCAQE, research undertaken by Professor Furlong on identification of TCP biomarkers and the effect on gene expression to TCP exposure as well as the Royal Australian Air Force view on contaminated air exposure. The Norwegian energy workers union, SAFE and the Norwegian Airline Pilots Association, hosted a 2008 conference in Stavanger, Norway. It focussed specifically on the contaminated air issue, with the offshore oil workers facing the same problem due to use of turbine engines (using synthetic lubricants) on the offshore platforms and other energy production facilities. Presentations were given by those who had experienced the effects first hand in the both the aircraft and on the oil platform as well as an overview of the OHS implications, toxicology, monitoring and use of oils without TCP.

There have been a range of other conferences that have touched on the contaminated air issue to varying degrees over the years ranging from the 1999 Californian SAE world Aviation Conference, 2000 Houston Aerospace Medical Association Conference, the 2000 Brisbane International Conference on Occupational Health and the 2001 Brisbane Congress of Toxicology. More recently the ASTM 2008 International Symposium on the Airliner Cabin Environment in Los Angeles, looked at results of recent studies into a range of cabin issues. [559] However, no matter what data has been presented, the issue remains far from resolved.

2.8.12 To Summarise

There have been numerous conferences and inquiries over the years reviewing the contaminated air issue to varying degrees. There is a clear divide between the few independent or semi-independent inquiries that have been relatively free to make strong recommendations and those that clearly have placed the industry needs ahead of the issue at hand. To date, the conferences and inquiries that have looked at the data in some detail in a reasonably independent manner, have been affected by lack of resources. However, the data have been clear enough to make strong conclusions and recommendations. Despite this, the airline industry has gone to great lengths to cherry pick, ignore or manipulate these conclusions and recommendations, instead suggesting there is insufficient evidence.

2.9 The Industry and Government Positions

2.9.1 Introduction

Over the years there has been a slight shift in the industry and Government positions regarding the contaminated air issue, however it has really shifted from almost straight denial to damage limitation bordering on denial. There are a number of consistent themes that continue to be utilised to diminish the health and flight safety consequence of aircraft contaminated bleed air. These will be briefly reviewed followed by a breakdown of the various industry dominant positions. Extensive supporting evidence has been published. [560] The repeatedly used position statements include but are not limited to:

- Contaminated air events are very rare (episodic) and therefore not a great health and flight safety issue;
- Oil fumes do not effect flight safety and are a comfort issue only, possibly an occupation health issue;
- TOCP is too low to be a concern;
- There is no evidence of synthetic jet engine oils causing harm to humans in an aircraft;
- All identified substances are below exposure levels;
- The evidence is inconclusive;
- The symptoms seen are not caused by oil/fluid exposure;
- The chemicals are at best irritants and are not toxic;
- All evidence is anecdotal; There is no evidence
- Oil is not harmful by inhalation;
- Aircraft air quality is fine under normal operations;
- More research is required;
- We have no idea what is in aircraft contaminated bleed air;
- There is no link between contaminants from bleed air and ill health;
- All the aviation and OHS regulations are met;

- The problem is fixed;
- No fatalities (for technical reasons) mean the aircraft are safe;
- The problem is all in people’s heads; it’s simply a crew perception;
- Crew impairment in flight is low and therefore not a safety issue;
- Regulator’s are not responsible and contaminated air is outside their expertise;
- Scientific proof is required before any action can be undertaken.

The above positions are firmly entrenched. No matter what evidence is available, even if it originated within the airline industry itself, the industry and government position put forward publically virtually does not change.

Two brief examples with appropriate comment include:

1. Contaminant levels are safe.

- Airline: *‘In National Jet’s experience contamination does not occur at levels which exceed permitted levels.’* [126]

Comment: Airline had not undertaken any testing

- Mobil: *‘The risk assessment showed that a potentially harmful dose is not possible via inhalation at levels at or even higher than TLV of 5 mg/m.’* [183]

Comment: Oil mist exposure standards are not applicable to synthetic jet engine oils (or other toxic oils).

- Engine and APU manufacturer: *‘The quality of the supply air for the cabin and cockpit is within safety limits.’* [255]

Comment: Allied Signal was aware it had found contaminats at 4 times the level it accepted in it’s own own maintenance procedures; found the presence of TCP (which does not have a safety limit) and recognized available safety limits were outdated. [255,561,562]

2. The oil is not harmful via inhalation.

- Airline Chief Medical Officer: *‘TCP is a toxic mixture that can cause a wide array of transitory or permanent neurological dysfunctions when* *swallowed. However, there have been no recorded cases of neurological harm in humans following dermal or inhalation exposure. This means that the substance can be potentially harmful if swallowed in large enough quantity, but is not harmful if absorbed through the skin or breathed in.'* [366]

Comment: MSDS and other toxicological data warn of inhalation risks.

- Oil manufacturer: *'An accidental contamination of the entire body surface with an oil containing 3% TCP for 6 hours would not result in the absorption of more than an estimated non toxic single dose... It would be virtually impossible for a person to receive enough of the oil in the normal workplace (or in an aircraft) to cause such toxicity.'* [183]

Comment: MSDS and other toxicological data warn of inhalation risks. Mobil has not conducted any inhalation testing.

2.9.2 The oil manufacturers

Essentially, the major oil manufacturers have conducted their aviation lubricant business in isolation and without any form of regulatory control. The toxicological testing undertaken has been completely inappropriate, using the wrong method of exposure (oral, dermal) on cold oils or the individual ingredients of the oil, with the assumption that ingestion was the worst case scenario. This is despite Mobil's 1983 awareness that the USAF had previously undertaken inhalation studies of heated oils, which indicated hazards, that were incorrectly interpreted by the lubricant manufacturer downplaying the findings. [146147,459] There has been a complete refusal to look at any form of human effect other than OPIDN and minor gastrointestinal effects with blanket denial that any form of human toxicity from exposure to jet engine oils was remotely possible. [183,226] This has occurred despite Mobil's own acknowledgments of limitations in the testing undertaken. Until the 2000 Australian Senate Inquiry, the only public acknowledgment about the ortho isomers of TCP referred to the low levels of TOCP, yet Mobil advised that in fact, the more toxic ortho isomers of TCP were in the oil at far higher levels with increased toxicity and this had been known for 40 years. [183,226] Even still, this did not lead to a review of the oil manufacturer's position or alter their continued refusal to look at the evidence. The mislabelling of the MSDSs has gone unchecked for years and the legalised dominant industry position could be seen in the 2004 reaction to the OSHA citation over it's mislabelling of the engine oils in which OSHA backed down. [286,287,288] Mobil has remained untouchable and insisted it is a responsible manufacturer which had been *'forthright, responsive and thorough in providing input'* regarding its oils, which had been acknowledged at numerous inquiries and in various studies. [563] However, at the end of the day, Mobil advised that leaking oils into aircraft cabins is not what it considers *'normal use'*, yet has continued to do nothing to address the problem. [183,184] Perhaps the Mobil position is a consequence of their own admission that *'The profit on this product is not high enough to support a very expensive research program by the oil manufacturers and little would be lost to a manufacturer by simply dropping the product'*. [280]

On the other hand the small French oil company NYCO is the exception to the dominant and closed position shown by the oil manufacturers. In the late 1970s NYCO removed TCP from its oils as a consequence of being advised of the hazardous nature of TCP by the French Government. Likewise, NYCO has recently announced it has reviewed its current oil and alternative substances and found that TCP presents a *'non-negligible'* inhalation hazard and its own use of TIPP *'did not present a significant improvement'* over TCP usage. [222] Therefore NYCO has commenced once again to develop new oils. This is a commendable and outstanding industry action.

Interestingly the (military) specifications to which synthetic oils had been required to adhere to stated that with regard to toxicity, the oils should have *'no adverse effect'* on human health when used for it's intended purpose. [564] However, the recent change to a civilian standard has removed this requirement. [565] Additionally, it had been assumed that the lower concentration of ortho cresol isomers were protective (in terms of OPIDN), however toxicity concerns were still raised even with ortho content below 0.2% of the TCP, yet no changes have occurred apart from the NYCO actions, however the new NYCO oil is yet to be certified.

2.9.3 Aviation regulators

The position of the regulators varies a little internationally, however all end up in the same position of doing almost nothing to address the problems, other than to manage the problems for the industry benefit. For example CASA in Australia viewed that oil fumes were outside its expertise and that as an aviation safety regulator, it was responsible for only short and medium term effects on air safety and aircraft oil fumes were not considered an engine defect as crew were affected differently. [45,121,122] The UK CAA steadfastly has vocally continued to minimise the effects of oil fumes [40] on air safety and health, initially suggesting the low level impairment effects being seen were not its direct responsibility, while long-term health certainly was not either. This has changed a little, given changes to the law in the UK regarding the CAA responsibility for crew and passenger health and the CAA/HSE MOU. However, while the CAA has been given the requirement to address OH&S issues, the OH&S legislation is not available to crews or an aircraft inflight, even though under law it should be. The CAA has placed all it's efforts in limited studies being undertaken by the Department of Transport trying to determine what is in the air. [70,342] The FAA has remained very quiet over the years, doing very little, despite acknowledging in 2002 that aircraft were not in fact airworthy as no detection systems were fitted, however no action has been taken to date to address the root cause of the problem. [18] All other regulators have effectively ignored the issue to date and allowed the industry to self regulate with regard to contaminated air. There has been a slight change in recent years, however with some acceptance that there may be a problem, but more research is requested (on their terms and timetable). CASA has initiated a new expert inquiry, while the FAA has been required by congress to fund research through the ACER/OHRCA research consortiums, however little effective research has come out of this (apart from a medical protocol), with much attention devoted to other issues and the research 7-8 years later is still ongoing. The UK regulator has formed a tight coalition with the Department of Transport, Aircraft Health Unit and Aircraft Health Working Group that all outside parties have effectively been excluded from. EASA has recently announced a proposed amendment to regulations; however its stated position is almost identical to the CAA. [39] The bottom line is the regulations regarding contaminated air are failing to be met and the regulators have taken no action apart from now suggesting more research is required.

2.9.4 Aerospace manufacturers

The airframe, engine and APU manufacturers have, like the oil companies such as ExxonMobil, remained at arm's length. While there is considerable data available particularly regarding British Aerospace, there is less information publicly available from others. A strong partnership of denial has been formed by airlines, regulators, other manufacturers and governments regarding the contaminated air issue. As an example, the German Aerospace industry coallition recently prepared a common confidential postion statement regarding contaminated bleed air. [566] The BDF, according to the media, aimed to find a common point of view amongst it's members so as to issue a co-ordinated response to protect itself from legal threats and raised passenger awareness which could effect passenger numbers. Essentially, the position was that TCP in aircraft air was not a problem according to scientific evidence and in normal operations oil would not enter the air, hot bleed air filtration was not possible and there was no alternative to TCP. The regulators and other industry partners have placed a strong reliance upon manufacturer led research without questioning the independence and with the almost total exclusion of aircrew and their representatives. For example, the BAe work undertaken with DERA in the UK was confidential for many years, with the CAA even given only limited access. However, the CAA was willing to use this confidential, non-independent data and accept that limited adverse health effects could occur based on this report. [252,567,568,569] Yet the CAA refused to accept that under reporting of fume events was occurring, even after both pilot unions advised the CAA this was occurring, as presumably, to accept that under reporting was occurring would not be in the CAA or the industries better interest. While British Aerospace publicly insists its aircraft have caused no problem, the service bulletin history and its admission to the Australian Senate indicate otherwise. [11,34,123] Rolls-Royce on the other hand when asked to participate in discussions regarding contaminated air by a pilot union, it advised it's position was that: [570]

- *'Aircraft engine bleed air quality is addressed in the certification requirements which must be met before an engine can enter service. Correctly maintained and operating Rolls-Royce engines comply with all applicable certification requirements. What is sometimes referred to as "cabin air odour" may arise from a number of sources including APUs, engine bleed air and galley food smells. In the event that potentially engine related cabin air odour is detected, Aircraft Operating Manuals explain the steps which should be taken.'*

When asked four years later to engage in discussions with the GCAQE (for which the author is head of research), Rolls-Royce (on behalf of the CEO) advised that *'We are engaged with the CAA and are supporting the studies into cabin air quality in a rigorous and scientific manner. We review regularly the published data on this topic and try to stay abreast of any developments. Therefore we do not believe that a meeting with your group would lead to any greater understanding of the issue.'* [571] British Aerospace's CEO representative's response to the GCAQE was little different stating *'BAe as you know takes the subject of cabin air quality very seriously and in consequence we maintain close and active relationships with the relevant regulators and other appropriate authorities in this regard. Given the circumstances, I do not think it is appropriate to take up your offer.'* [572]

The following statements fairly well sum up the manufacturer positions:

- *'Boeing is committed to providing a safe, healthy, and comfortable cabin environment for passengers and cabin crew. Air quality studies conducted over the years by government agencies, independent researchers, universities, and industry have shown that contaminant levels are generally low and consistently comply with applicable health and safety standards. In addition, current regulations and industry specification and design practices seek to minimize potential sources of bleed air contamination. Boeing and the industry as a whole have been quite successful in achieving that goal, as indicated by the very low frequency of bleed air contamination incidents reported to regulatory and industry databases. Currently, there is no data indicating that bleed air contamination is adversely affecting the health of aircraft crew or* *passengers. Ongoing research continues to improve our understanding of the cabin environment and its relationship to passenger health and comfort, and we continue to work with scientists to improve our understanding of cabin environmental factors.'* [573]

- *'Airbus has for many years continuously strived to set standards on cabin air quality, the safety of our aircraft always being our number one priority. However Airbus does not believe that your opinions are supported by currently available peer-reviewed scientific evidence. Airbus has provided supporting evidence to a number of enquiries …Airbus aircraft are designed to avoid cabin air contamination in normal operating conditions.'* [574]

Whilst all aircraft currently flying use bleed air, Boeing should be applauded for the introduction of a *'bleed free'* architecture on its Boeing 787 that first flew in December 2009. Boeing has paved a way forward which hopefully all other aircraft manufacturers will follow in the future. However, when asked to consider bleed free technology, Airbus responded suggesting that *'the benefits of alternative cabin air supply architectures are not currently proven'* and that the industry as a whole had *'under development a number of other aircraft using eco-efficient air supply architectures based on bleed air.'* [574] Boeing when asked about the ASHRAE recommendation of (investigating) fitting filtration and bleed air sensors to all current commercial aircraft advised that *'we do not agree with that recommendation and the best technical information currently available on this topic does not support that recommendation.'* [575]

However, there are some current limited initiatives that some manufacturers have adopted. For example Boeing and Honeywell have developed ground based oil detection kits, along with Lufthansa (refer air monitoring section of thesis), while BAe is trialing and globally marketing the Quest Air Manager as a *'new standard in cabin air quality.'* The Quest system uses a close coupled field Technology, a form of non thermal plasma oxidation to remove particulates and VOC odour compounds. However this technology has been viewed as problematic by airlines and industry. [170,180]

2.9.5 Occupational health and safety regulators

The occupational health and safety commissions role in the contaminated air issue, despite regulations being available and required to be met, have done and continue to do almost nothing. In the US case, OSHA has handed over complete OHS responsibilities to the FAA, while in Australia, the regulations apply; however, the state work cover authorities have almost entirely deferred responsibility to CASA. In the UK case, the OHS legislation applies, however there is a memorandum of understanding deferring almost all responsibility to the CAA, which does not enforce the OHS legislation. [115,116]

2.9.6 The airlines

Initially, airlines dealt with the cabin air contamination issue in isolation with the manufacturers where necessary. This has more recently moved to an industry alliance with the airline positions summed up quite clearly as a carefully repetitively worded exercise of damage control. A recent public relations release from British Airways shows this quite clearly by the way in which the airline responded to a number of questions relating specifically to contaminated air. [576] Key elements provided by the airline were that:

- *'The health and safety of our staff and passengers is of utmost importance to us; we would never operate an aircraft which we believed posed a health or safety risk; we have always taken our responsibilities in matters of health and safety very seriously and provide active support to a number of independent and international aviation medical organisations; we also work closely with industry groups, medical professionals and regulatory agencies to ensure we deliver the highest levels of care to our customers and employees; we believe there is little independent scientific evidence to support any view that there is adverse effect on the health of passengers or crew members from travelling in a pressurised aircraft cabin; several recent studies have been conducted into cabin air quality, including the European Union's Cabin Air project and the United States' ASHRAE study. Both have confirmed the results of previous studies that cabin air quality is generally at least as good as, and often better than, that found in domestic or office environments,* *other than the known issues of low humidity and reduced level of air pressure. Further more, the UK CAA is a participant in the EU Ideal Cabin Environment (ICE) project, which aims to build on the previous research and deliver final outcomes and recommendations; the Committee on Toxicity (COT) has undertaken a comprehensive review; we are aware of incidences where the crew have complained of fumes in the cockpit. In conjunction with the CAA these incidents have been fully investigated and it was found that there were no health implications associated with these cases; we take all reported incidences of fumes seriously and investigate them as a matter of priority.'*

2.9.7 Governments

The European Government positions on the cabin air issue have evolved from allowing the regulator's to address the issue or otherwise, to now one of control from the top down. In the UK case the Department of Transport has led the alliance since the findings of the 2000 House of Lords report. One further problem has been that committees such as the 2000 House of Lords Inquiries were not sufficiently given the time or expertise to really understand the issues and hence were very easily manipulated by the industry without realizing this. The position has been to ensure all Government industry alliances provide a co-ordinated response leaving in effect no room for inclusion of outside parties. Examples include the 2003 BRE study, the 2004 CAA Cabin Air Quality study which utilizied BAe/DERA 2001 data, the 2006/2007 Committee of Toxicity studies and the ongoing UK Cranfield monitoring studies. All of these have been undertaken and analysed for suitability almost entirely within the closed circle.

Two calls were made for public inquiries by the GCAQE in the UK in 2008 and 2009 supported by the 3 main opposition parties. However these were ignored by the British Government, which regarded that there had already been 2 public inquires, specifically the UK COT inquiry of 2006/2007 and the 2007 follow up House of Lords inquiry and there was little point in another. [548]

The US and Australian Governments appear only slightly less controlling, with Australia establishing a further inquiry and the US House of Representatives and Senate approving the FAA Reauthorisation Act and FAA Air Transportation

Modernization and Safety Improvement Act directing the FAA to *'begin research and development work on technology that will be able to detect highly toxic contaminants in the air supply and to filter out the contaminants'.* [577,578] However the FAA ACER work, which commenced in 2003, funded by the FAA, (see inquiries section, section 2, NRC) in effect set out to research exactly this, however 7 years later has not progressed far and appears forgotten.

The FAA and EASA responses to the ASHRAE request asking for the regulator's to immediately undertake this type of research was stalled in 2009 as the FAA, via its current research, was already trying to determine how best to address air cabin air quality. [579] A similar response was received from EASA. [580] The European Commission has, in conjunction with industry partners, undertaken several projects, including the 2003 CabinAir study that ignored contaminated air and the 2008 ICE project that did not use bleed air as part of it's study. Both studies, however, have insisted that cabin air quality is satisfactory. The CabinAir study from 2003 has led to the recently published European air quality standard EN 4618. However, the flaws in the standard (in addition to ignoring oil contamination) have been semi-officially recognized by EASA and ASD-STAN along with the recognition that the standard will require amendment. The EU Industry dominated ICE project, which led to the draft standard pr EN 4666, has also been criticized as inappropriate and failed the initial EU ballot. [339,581,582,583,584] In reality, both standards are industry-dominated standards made for the European Aerospace industry. The EU, along with industry funding on the various air quality projects that have not included contaminated air, have amounted to approximately 57 million euros of which EU funding has amounted to around 31 million euros. [585] It is understood that ASD-STAN is likely to work with EASA, based on it's A-NPA results to address the flaws in 4618 as part of the EASA led research likely to be undertaken in 2011. [584]

Interestingly, Senator O'Brien of the Australian Senate who sat on the original Senate Inquiry committee in 2000 advised the Australian parliament in 2008 that the Parliament had *'effectively been lied to by Australian operators.'* [586] Senator O'Brien questioned if the Parliament, Regulator and Courts had been misled in relation to the BAe 146 withheld information. [587] The general industry practices are in reality little different.

2.9.8 Aircrew unions

The current lead coalition dealing with contaminated air is the Global Cabin Air Quality Executive (GCAQE). The GCAQE was established in 2006 to specifically address the contaminated air issue and represents a large number of unions globally that have come together to address these issues in a united manner. With the exception of those unions who are currently members of the GCAQE, most aircrew unions have done little to address the ongoing contaminated air issue.

The ITF had pursued these matters but has done less since the creation of the GCAQE.

In contrast, IFALPA has done little to challenge the powerful industry alliance. [588,589] One of IFALPA's most influential members, the British Airline Pilots' Association stated in 2008 that *'There were 'no solution/no plan B' to this problem. It was imperative for BALPA to work with those who stood the most to lose from this issue - those that could be sued, the airlines, manufacturers and those they work with such as the Government and CAA'.* The BALPA position being summarised as *'the main issue was to prevent those defending their products from being sued and as such the collapse of the industry'.* [590]

2.9.9 To Summarise

In 2009 when both the FAA and EASA were asked to begin immediate research into detection and air cleaning technologies by an ASHRAE expert committee on contaminated air, the US FAA ignored the call and suggested they were waiting on an additional ASHRAE report determining how best to move forward and the results of the FAA funded ACER research. [579] EASA suggested it did not need to undertake such research as it was relying on studies from Cranfield, ACER, ASHRAE and OHRCA. [580] This is despite the fact that contaminated air is an airworthiness issue that must be addressed for an aircraft to be deemed airworthy, a fact completely ignored by the FAA and EASA. The industry alliance in general has moved from a fragmented approach to a powerful coalition that ignores or manipulates all outside data and works towards an industry required solution suitable to its partners, in a manner previously only seen within the tobacco industry. Effectively all data that recognizes there is a problem has been brushed aside in favour of more reseach that is going around in circles and ignores that the toxicity of heated jet engine oils was recognised in 1954.

2.10 Thesis Proposal

This thesis considers the tensions between aviation professionals who focus on air safety as a priority, sometimes at the expense of the safety of the travelling public (passenger safety) or workers (occupational health and safety). This focus is commercial – it is a rubric in this industry that aircraft only make money when they are flying, so anything that might impact on this will be resisted.

By using cabin air quality as an example, the issues of how poor air quality may impact on worker and passenger health and safety will be examined, using the specific example of jet oils leaking into bleed air, and being passed through to the flight deck and passenger cabin of airplanes. There have been indications that the health problems associated with these exposures may be linked to such exposures, and a suggestion that they may cause a specific health condition.

The structure of the remainder of this thesis is:

Chapter 3: Thesis aims;

Chapter 4: Examination of symptoms and health effects reported by aircrew exposed to contaminated air in 3 descriptive epidemiological pilot surveys and a discussion of the existence of a discrete health condition called aerotoxic sydrome;

Chapter 5: Review of the various synthetic lubricating oil and air monitoring studies, investigating air quality in aircraft and the suitability of using these studies to determine suitability of assessing aircraft air in terms of health and safety;

Chapter 6: Review of the various databases that collect information on oil leak incidents in this industry to determine frequency of fume events;

Chapter 7: An examination of industry based documents about what was understood within the industry about this issue and its possible impacts;

Chapter 8: Discussion, conclusions and recommendations.

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3 The Aims of this Research Thesis

3.1 Aims of this Research Thesis

The aim of this thesis is to investigate various aspects of exposure of aircrew (pilots, cabin crew) to contaminated bleed air in aircraft. Areas covered will include toxicology, flight operations, flight safety, regulatory, health and occupational hygiene (workplace monitoring). By reviewing all areas together, it should become evident what role contaminated bleed air has in aviation today, from both a health and flight safety implication.

3.2 Research Objectives

The objectives of this thesis are:

- Review health problems reported by aircrew when exposed to contaminated bleed air whilst flying and undertake a health survey of BAe 146 pilots exposed to contaminated air in aircraft;
- Review aviation air monitoring studies that have been undertaken to assess the quality of bleed air and their usefulness in determining effect on health;
- A review of the frequency of contaminated bleed air events will be undertaken along with their implications for flight safety;
- Information known by the aviation industry about contaminated bleed air will be reviewed to determine if appropriate actions have been undertaken;

3.3 Research Questions

The research questions of this thesis are:

- What health effects are being reported in crew exposed to contaminated bleed air?
- What monitoring has been undertaken, what was found and can such data be used to assess exposure impact on human health?
- How often do contaminated bleed air events occur and what are the flight safety implications?
- Have the aviation industry and Governments dealt with the contaminated bleed air issue appropriately?
- What are the effects of exposure to contaminated bleed air?

3.4 Research Methods.

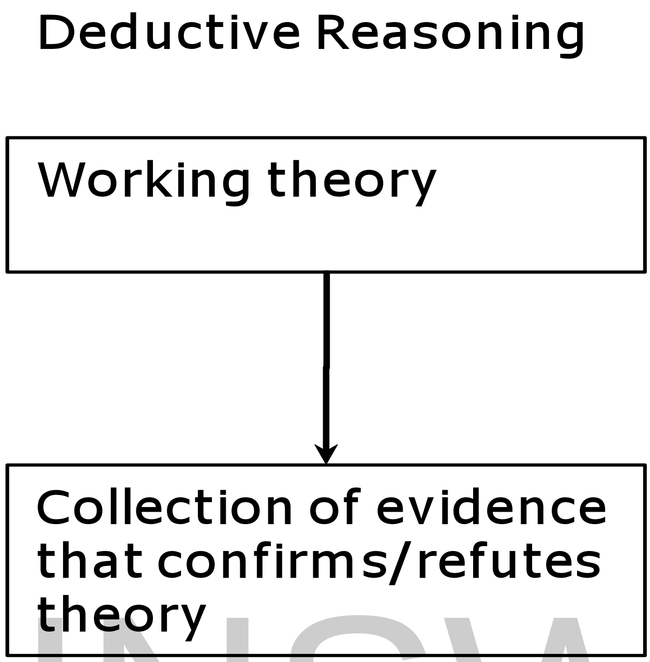
Mixed Methods as a Research Technique

In keeping with the methodologies of conventional research, this thesis is a research project that was conducted using a variety of methods and approaches. These various activities were useful because they generated findings that contribute to a larger picture than could be explained by a single study. Because of the nature of its research questions, it was difficult to separate out and prioritise the individual components of the project because they overlaped and were ultimately inextricably intertwined. The various strands of scholarship, qualitative and quantitative approaches are like the strands that make up a cable, and can, when all bound around each other together, be considered a better, amalgamated whole.

This research therefore used mixed methods as a means of developing a more complete picture of the research topic. A mixed methods approach is becoming more common in research and is defined as a procedure for collecting, analysing, and mixing both quantitative and qualitative data into a single tangible concept. [1]

Qualitative research (see Figure 3-1) tries an open-ended approach based on a working theory to obtain key answers from a non-random sample through the collection of non-numerical data or from explanation based on the attributes of a source of data. [2,3] Selection of such samples is purposive, rather than random, and is based on indicative, sentinel or otherwise significant sources. This process is deductive, in that it can confirm, or lead to modification, or refute research questions. It can also generate ideas that can be used to create further research questions for later study. [4]

Figure 3-1: Qualitative Research



The goal of quantitative research is to obtain numerically based answers from a representative sample or samples. A reductionist, purely scientific approach is most applicable to research situations that can be controlled and are repeatable, and generate sufficient data from representative sample. [5] Such situations allow the collection of quantitative numerically based data that can be analysed using standard statistical methods. [6,7] As such, quantitative research (see Figure 3-2) is inductive, in that data is collected and analysed to see if any patterns emerge, from which it may be possible to generate generalisations, theories or models.

Therefore, mixed methods research (see Figure 3-3) combines these approaches. It is empirical research that involves the collection and analysis of both qualitative and quantitative data. This is research where more can be learned about the research topic by combining the strengths of qualitative research with the strengths of quantitative research, by applying different approaches at any or all of a number of stages through the research. [8]

Figure 3-2: Quantitative research

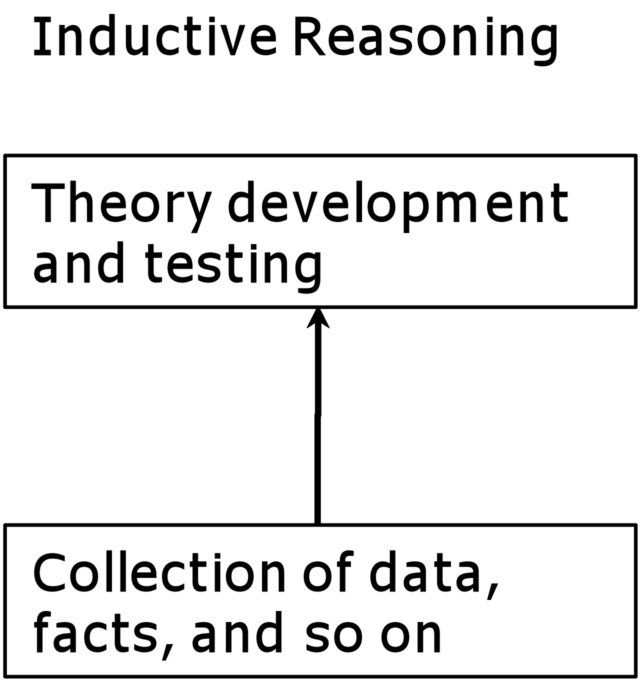
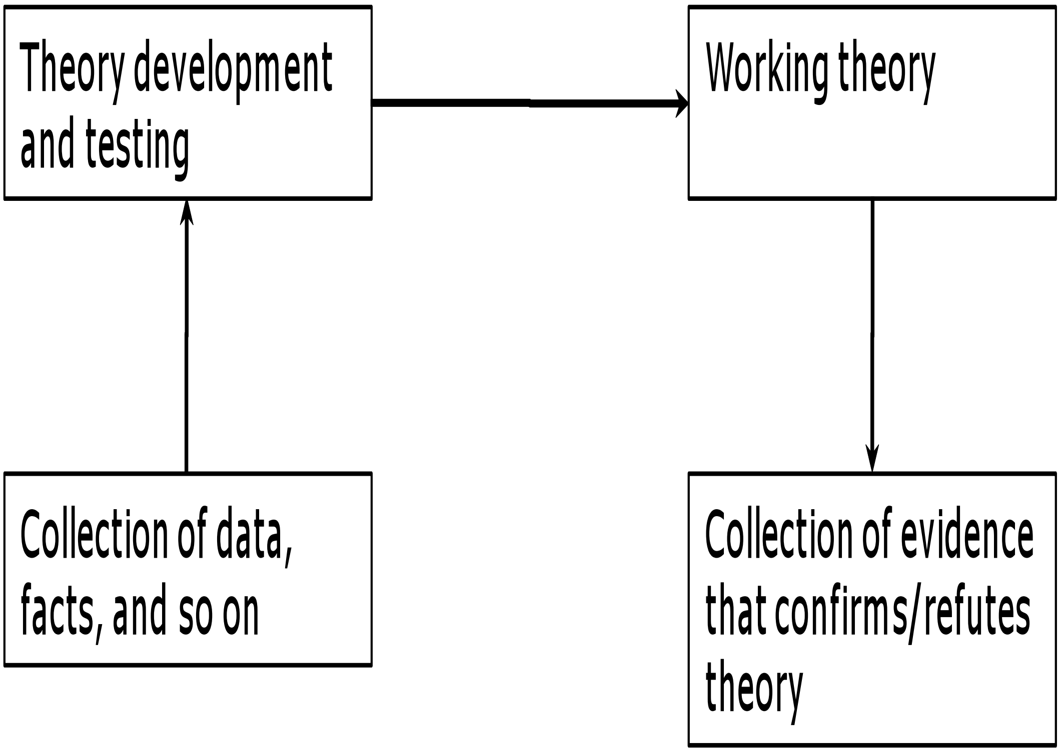


Figure 3-3: Mixed methods research



There are advantages and disadvantages in doing this. Advantages include using different methods to examine different types of phenomena is often resource efficient. Some methods may not be ethical, useful, desirable or even possible, especially where data are difficult to obtain. Indeed, the mixing of methodologies within a broad quantitative or qualitative approach may raise almost as many issues as when working across approaches. [9]

The combination of methods used, and the availability of the different interpretations they can generate, amount to conducting different studies with the aim of generating findings that support and build the same final conclusion (providing that such a conclusion was not an artefact of method and each method had predictable and measurable sources of error). Mixed methods are useful because the different approaches will tend to cancel out any methodological differences and systematic errors, and any potential conclusion that might arise will do so in spite of such biases, not because of them.

One thing that mixed methods research can do that is not an end product of other research approaches is that, at the end of the various activities that make up the research project, the end result is usually greater than the sum of its individual qualitative and quantitative parts. [10]

Mixed methods are used to enrich understanding of an experience or issue through by initiating new ways of thinking about the subject of the research, extension of knowledge or confirmation of conclusions.

Therefore, it becomes necessary, to clarify just what is being mixed - and how it is being mixed. The *'mixing'* may be nothing more than a side-by-side or sequential use of different methods, or it may be that different methods are being fully integrated in a single analysis. [11]

However, there are a range of mixed methods approaches, including, triangulation, convergence, embedded and accretion methods:

Triangulation is the combination of at least two or more theoretical perspectives, methodological approaches, data sources, or data analysis methods. It is the commonest approach used in mixed methods research, and the purpose of this approach is to obtain complimentary data regarding the same issue. [12]

Triangulation strategies do not strengthen a flawed study, but are usually used to decrease or counterbalance the deficiency of a single strategy, thereby increasing the ability to interpret the findings. [13]

Convergence is the availability of data complementarity, which avoids premature closure, allows the development of different interpretations, and helps assure proportionate weighting of findings from different approaches. In some cases, convergence across different perspectives or research methods, builds a better picture of the issue being studied. [14]

Embedded methods are where one data set (of either the qualitative or quantitative type) provides a supportive role in a study of mainly the other type. [12] Such studies must be designed properly at the outset.

Lastly, there is a combination of triangulation and convergence approaches, where the increase of findings by addition or accumulation (accretion) from studies looking at an issue from different perspectives and using different research methods, generates findings that provide a better quality understanding of the issue under study. [15]

Mixed Methods in this Thesis

The methods used in this thesis, as detailed in other sections, include:

- Critical analysis of published literature, especially health effects, air quality studies, and toxicology information;
- Review and analysis of unpublished information, such as oils, MSDS and labels, incident reports, engineering reports, use of bleed air systems and company correspondence;
- Legislative review; Aviation and occupational health and safety;
- Three descriptive epidemiological surveys of flight crew on two modes of airplane in two different countries;
- Flight safety aspects;
- Government and airline industry postions and actions.

Sometimes, the reason for choosing a mixed methods design is not made clear by the researcher at the outset, potentially leading to confusion in the design phase of the study. [16] Some of the purposes necessitating mixed methods may be initiation, expansion or corroboration. [17]

In this thesis, the mixed methods approach allowed specific aspects identified in earlier studies to be followed up, in some cases, using different methodological approaches. For example, the broader findings of the analysis of workers compensation data analysis and workplace surveys lead to identification of specific factors that required follow up with a survey of industry based key informants. This triangulation allows validation by corroboration. [18,19]

A further outcome of the mixed methods used in this survey will be reviewed in the discussion section of the thesis.

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4 Symptoms and Health Effects Experienced by Aircrew and Passengers

4.1 Introduction

Many sectors of the airline industry have advised that there is no evidence of ill health amongst aircrew or passengers related to the use of bleed air in aircraft cabins. [1,2,3,4,5,6] This chapter reviews some of the published studies looking at exposure effects of aircrew exposed to oil/hydraulic fluid leaks in aircraft, and outlines the results of three surveys of pilots in Australia and the United Kingdom, on two different models of aircraft. This is followed by a review of what the scientists and doctors are finding in aircrew and passengers who report exposure to aircraft contaminated air and ill health.

The oils and hydraulics used in aircraft engines can be toxic, and specific ingredients of oils can be irritating, sensitising and neurotoxic, (such as phenyl-alpha-naphthylamine and triaryl phosphates such as tricresyl phosphate). [7,8,9] If oil or hydraulic fluid leaks occur, this contamination may be in the form of unchanged material, degraded material from long term use, combusted or pyrolised materials. These materials can contaminate aircraft cabin air in the form of gases, vapours, mists and aerosols. There are a number of possible situations that can arise whereby aircraft cabin air can become contaminated. [10] Significant contaminants include: aldehydes; aromatic hydrocarbons; aliphatic hydrocarbons; chlorinated, fluorinated, methylated, phosphate and nitrogen compounds; esters and oxides. [11,12,13] One additional factor to consider during an exposure in the cabins of planes flying at altitude is that both oxygen partial pressure and concentration decrease with altitude. [14]

Oil leaks from an engine at high temperature and pressure may burn or pyrolise before entering the cabin air, generating many combustion and pyrolisis products that are toxic. [13] Such products may contain a complex mixture of substances including carbon containing materials such as CO_2 and CO. Short-term exposure to CO produces headaches, dizziness and nausea, while long-term exposure can cause memory deficits, CNS damage and other health issues. [15] Partially burnt hydrocarbons such as acrolein and other aldehydes are highly irritating, while others such as oxides of nitrogen and phosgene can produce delayed effects. [16] Particulate matter can carry adsorbed gases deep into the respiratory tract where they may produce a local reaction or be absorbed to produce systemic effects.

To date, most studies that have been carried out to measure atmospheric contamination in aircraft by engine oil leaks or hydraulic fluids are sufficiently flawed on procedural and methodological grounds as to render their conclusions invalid. Further, virtually no monitoring has occurred during a leak and human effects studies have not been undertaken at the time of the limited monitoring in abnormal conditions.

International aviation legislation such as the US Federal Aviation Regulations (FAR) and airworthiness standards for aircraft air quality state there must be sufficient *'uncontaminated air to enable crewmembers to perform their duties without undue discomfort or fatigue'* and that *'crew and passenger compartment air must be free from harmful and hazardous concentrations of gases or vapors'.* [17] Where contamination of air in flight deck and passenger cabin occurs that is sufficient to cause symptoms of discomfort, fatigue, irritation or toxicity, this contravenes such standards and legislation. [9]

A 2005 health perception survey provides a background to health problems in aircrew. [18] Common symptoms reported by aircrew were: fatigue (21%); nasal symptoms (15%); eye irritation (11%); dry or flushed facial skin (12%) and dry/itchy skin on hands (12%). The airline crew had more nasal, throat, and hand skin symptoms than office workers.

Where exposure may be to high levels of airborne contaminants, it is not unreasonable for signs of irritancy and discomfort to be observed. Similarly, it is not unreasonable to consider that a person exposed to a chemical that contains 1% of a sensitiser and 3% of a neurotoxicant might show signs of irritancy and neurotoxicity. These symptoms are often reported in aircrew who may be exposed to aircraft fluids. [9] In terms of toxicity, a growing number of aircrew are developing symptoms following both short term and long term repeated exposures, including dizziness, fatigue, nausea, disorientation, confusion, blurred vision, lethargy and tremors. [19,20,21] Neurotoxicity is a major flight safety concern especially where exposures are intense. [22]

Inhalation is the most important route of exposure, followed by exposure of uncovered skin being (for example, following exposure to oil mists or vapours). Ingestion is unlikely within the aircraft environment unless food and liquids are being consumed during or after a contaminated air event.

There is no central database for the collation of aircrew health effects reported after contaminated air events. [23,24] Passengers are virtually never advised such events are suspected to have taken place and will likely not associate any possible connected health effects after a flight with a malfunction in the cabin air supply. There are a variety of reporting formats for crew related to air quality events. However, most do not involve reporting health effects and certainly not any ongoing longer-term effects. Most crews ought to be in good medical condition, especially pilots, as they are regularly checked by aviation doctors, at least annually. However, there is evidence that these pilot medical exams are not detecting the short or long term symptoms related to contaminated air exposures. Data on the impact of exposure to contaminated air by the general public such as the young, elderly or pregnant passengers and their unborn is completely unknown.

The earliest case of aircrew impairment found in the literature was reported in 1977. [25] A previously healthy member of a military C-130 aircraft flight crew was acutely incapacitated during flight with neurological impairment and gastrointestinal distress. His clinical status returned to normal within a day. The aetiology of his symptoms was related to an inhalation exposure to aerosolised or vaporised synthetic lubricating oil arising from a jet engine of his aircraft.

Other studies of exposures in aircraft exist in the literature, including a 1983 study of eighty nine cases of smoke/fumes in the cockpit in the US Air Force; [26] a 1983 study of Boeing 747 flight attendants in the USA (this paper linked symptoms to ozone) [27] and a 1998 study of BAe 146 flight crews in Canada over a four-month period. [397] A recent report of seven case studies considered representative of the common symptoms of irritancy and toxicity described similar symptoms, [21] and a follow up survey by the same research group reported similar findings in a larger group of fifty respondents. [28] These studies investigated different exposures and situations, and the range of symptoms in these studies was quite broad, affecting many body systems.

However, there are common themes in symptom clusters in these studies, as shown in Table 4-1.

While Table 4-1 shows a long list of symptoms, it is possible to characterise many symptoms more consistently. For example, different papers report dizziness or loss of balance or light-headed or feeling faint or feeling intoxicated or disorientation. It would be incorrect to regard such symptoms as being entirely different from each other – they point to a basic neuropsychological dysfunction affecting balance. But rather than dismissing such symptoms as being multitudinous and variable, [24] it may be more appropriate to re-categorise symptoms with clearer definitions, so that the artificial distinctions between symptom reporting can be clarified, and a shorter list of 'symptom clusters' be developed. [9]

Table 4-1: Studies reporting signs and symptoms in aircrew

Reference	[26]	[27]	[397]	[21]	[28]
Number of cases/reports	**89**	**248**	**112**	**7**	**50**
Irritation of eyes, nose and throat				7/7	
Eye irritation, eye pain	35%	74%	24%	4/7	76%
Blurred vision, loss of visual acuity	11%	13%	1%	4/7	50%
Rashes, blisters (uncovered body parts)				4/7	48%
Sinus congestion	35%	54%	5%	2/7	
Nose bleed		17%		1/7	4%
Throat irritation, burning throat, gagging and coughing	2%	64%	43%	2/7	76%
Cough		69%		2/7	12%
Difficulty in breathing, chest tightness		68%		3/7	62%
Loss of voice		35%		1/7	
Chest pains	7%	81%	6%	2/7	22%
Respiratory distress, shortness of breath, breathing problems requiring oxygen		73%	2%	4/7	62%

Reference **Number of cases/reports**	[26] **89**	[27] **248**	[397] **112**	[21] **7**	[28] **50**
Fainting/loss of consciousness/grey out	4%	4%		3/7	14%
Shaking/tremors/tingling	9%		3%	3/7	40%
Numbness (fingers, lips, limbs), loss of sensation			2%	4/7	
Dizziness/loss of balance	47%		6%	4/7	72%
Light-headed, feeling faint or intoxicated	35%	54%	32%	7/7	
Disorientation	26%		15%	4/7	
Severe headache, head pressure	25%	52%	26%	7/7	86%
Trouble thinking or counting, word blindness, confusion, coordination problems	26%	39%		6/7	58%
Memory loss, memory impairment, forgetfulness				7/7	66%
Behaviour modified, depression, irritability	26%	20%		4/7	40%
Nausea, vomiting, gastrointestinal symptoms	26%	23%	8%	6/7	58%
Abdominal spasms/cramps/diarrhoea	26%			3/7	20%
Change in urine		3%			4%
Joint pain, muscle weakness, muscle cramps		29%		2/7	38%
Fatigue, exhaustion				7/7	62%
Chemical sensitivity				4/7	72%

4.2 Aerotoxic Syndrome

The 2001 case study was undertaken on seven aircrew (pilots and flight attendants), who were exposed to chemicals through the contamination of the cabin air whilst flying. [21] The survey presented a wide range of symptoms reported by the crew from four airlines in three countries on three different model aircraft. The consistency between the symptoms was seen as 'quite remarkable' and compared closely with symptoms reported in the three earlier surveys. [397,26,27] The term Aerotoxic Syndrome was proposed in 1999 to describe the association of symptoms observed amongst aircrew exposed to hydraulic or engine oil smoke or fumes. [20,29] The symptoms were seen as sufficiently consistent to indicate the development of a discrete occupational health condition with Aerotoxic Syndrome used to describe it (aero refers to aviation; toxic refers to toxicity of exposure and associated symptoms).

Features of this syndrome are that it is associated with aircrew exposure at altitude to atmospheric contaminants from engine oil or other aircraft fluids, chronologically juxtaposed by the development of a consistent symptomology of irritancy, sensitivity and neurotoxicity. This syndrome may be reversible following brief exposures, but features are emerging of a chronic syndrome following moderate to substantial exposures. [29]

The symptoms were categorised into short and long term symptoms as follows: [21,29]

Symptoms from single or short-term exposures

- **neurotoxic symptoms:** blurred or tunnel vision, nystagmus, disorientation, shaking and tremors, loss of balance and vertigo, seizures, loss of consciousness, parathesias;
- **neuropsychological symptoms:** memory impairment, headache, light-headedness, dizziness, confusion and feeling intoxicated;
- **gastro-intestinal symptoms:** nausea, vomiting;
- **respiratory symptoms:** cough, breathing difficulties (shortness of breath), tightness in chest, respiratory failure requiring oxygen;

- **cardiovascular symptoms:** increased heart rate and palpitations;
- **irritation:** irritation of eyes, nose and upper airways.

Symptoms from long term low-level exposure or residual symptoms from exposure

- **neurotoxic symptoms:** numbness (fingers, lips, limbs), parathesias;
- **neuropsychological symptoms:** memory impairment, forgetfulness, lack of co-ordination, severe headaches, dizziness, sleep disorders;
- **gastro-intestinal symptoms:** salivation, nausea, vomiting, diarrhoea;
- **respiratory symptoms:** breathing difficulties (shortness of breath), tightness in chest, respiratory failure, susceptibility to upper respiratory tract infections;
- **cardiovascular symptoms:** chest pain, increased heart rate and palpitations;
- **skin symptoms:** skin itching and rashes, skin blisters (on uncovered body parts), hair loss;
- **irritation:** irritation of eyes, nose and upper airways;
- **sensitivity:** signs of immunosupression, chemical sensitivity leading to acquired or multiple chemical sensitivity;
- **general:** weakness and fatigue (leading to chronic fatigue), exhaustion, hot flashes, joint pain, muscle weakness and pain.

In 2002 a further more in depth voluntary mail out survey was undertaken with a group of 50 aircrew in Australia (96%) and the US, so as to explore the development of aerotoxic syndrome via a descriptive epidemiological questionnaire. [28]

94% reported that their adverse health symptoms occurred after an assumed exposure to oil gases and fumes in the cabin. 96% of respondents reported adverse symptoms immediately while flying or on the same day as flying, while 82% of respondents also experienced adverse symptoms that continued for at least one month from the time of exposure. 76% of respondents reported long term effects (6 months or more) that remained or developed after exposures.

42% reported mild symptoms that reduced on vacating the plane and subsided further after extended rest. 22% experienced severe symptoms and collapsed after exposure.

The 2002 survey provides a breakdown as shown in Table 4-1 of some of the key symptoms reported.

- High levels of irritancy symptoms including eye irritation (76%) and skin problems (58%) consistent with exposure to an irritant were reported.
- Respiratory irritation was common with respondents reporting high levels of breathing problems, chest tightness and wheezing. Adverse respiratory health effects in aviation have been reported previously. [8,19,21,26]
- Nausea and vomiting were reported by 58% of respondents.
- Neuropsychological symptoms rates were high including intense headache (86%); dizziness and disorientation (72%); performance decrement (including changes in cognitive function) (70%); memory and recall problems (66%) and balance problems (62%). The consistency of neurological symptoms was deemed striking, suggesting neuropsychological impairment of a general nature, as seen, for example, in exposure to volatile organic compounds, organophosphate compounds or carbon monoxide. [30,31,32]
- Neurological symptoms such as tingling were reported at 40%, tremors (30%), seizures or loss of consciousness at 14%. These are significant symptoms that point to a toxic aspect of the exposures with a neurotoxic component to other symptoms, such as vision problems or disorientation or balance problems.
- Infertility was reported by 33% of the female respondents, which is above the 7-10% estimate. [33] Neonatal death, higher rates of miscarriages and genetic problems in offspring were also reported.
- A range of multi-organ or general symptoms was reported with exhaustion and chronic fatigue reported by 78% and 72% of all

respondents respectively. Altered immune problems and joint pain and muscle weakness/cramps were reported at 36% and 38% respectively.

The 2002 survey endorsed the view that this syndrome is associated with aircrew exposure at altitude to atmospheric contaminants from engine oil or other aircraft fluids, temporarily juxtaposed by the development of a consistent symptomology including short-term skin, gastro-intestinal, respiratory and nervous system effects, and long-term central nervous, respiratory and immunological effects. This syndrome may be reversible following brief exposures, but features are emerging of a chronic syndrome following significant exposures. [9]

It is important to note that in all the seven member case study cases, [21] there was documented recognition that cabin air contamination had either taken place or was an ongoing feature within the airline with ill health officially related to the work (fumes/oil fumes) environment accepted. The 2002 survey is also supported by strong industry admissions/evidence that oil contamination is occurring. [34,35,36] Additionally exposure to synthetic jet engine oil and its degradation products has been acknowledged within the aviation industry as able to cause short term or irritant effects. [37,38,39]

The Aerotoxic Syndrome study highlighted that hydraulics and lubricants used in aviation contain a number of toxic and irritating ingredients. [13] Exposure to such contaminants if they get into the aircraft cabin air can produce symptoms of toxicity. [28] The symptom clusters in aerotoxic syndrome can be described as: [28]

- Symptoms of dysfunction in neurological function immediately after intense exposures, including loss of positional awareness, vertigo and loss of consciousness. If these symptoms occur in a pilot, they are a significant aviation safety problem;
- Symptoms of skin, eyes, nose and respiratory irritation immediately after exposure. Further exposures exacerbate the symptoms, often leading to other respiratory and cardiovascular effects;

- Symptoms of gastrointestinal discomfort immediately after exposure. While these recede with cessation of exposure, there is a suggestion that nausea and diarrhoea can persist;
- Some symptoms of impairment of neuropsychological function immediately after exposure, such as headache, dizziness, disorientation and intoxication. These symptoms become more debilitating after time, with problems of loss of cognitive function and memory problems emerging;
- General symptoms of exhaustion progressing to chronic fatigue. It was common for respondents to spend layovers, weekends and holidays sleeping for days to overcome the symptoms of exhaustion; and
- General symptoms of immune suppression developing some time after exposure, including food and alcohol intolerances, allergies and chemical sensitivity. These symptoms worsen with continuing exposure and may worsen even after exposure ceases.

The survey also highlighted that while the working population should in general be healthier than the general population due to the *'healthy worker effect'* [40,41] the aircrew surveyed displayed symptoms at far higher rates than the population backgrounds. Given that pilots undergo regular health assessments, they should in fact be fitter than the general population. [28,42] The survey raised significant issues for the health of aircrew but also demonstrated the serious risks to flight safety as well as highlighting the hidden fear for crews speaking out about health effects and the effect it could have on their job. Overall the need for a more in depth survey was demonstrated. It is important to note that passengers are not informed of exposure and there are few data available related to effects of contaminated air exposures on passengers.

4.3 The Health Surveys

As part of the research for this thesis, three separate questionnaire surveys of health issues in pilots were conducted.

A need for surveys of flight crew was identified in the late 1990's, and the author was approached by the Australian Federation of Air Pilots (AFAP) to provide assistance. AFAP is a trade union covering some pilots within Australia. The union had been aware of some concerns being expressed from the late 1980s as it had received complaints from members who crew the BAe 146 aircraft and who had experienced the smells inside the cabin and cockpit. The author was one of the union members referred to. Many of the reports being received by the union were very similar to nervous system disorders and seemed to appear after an exposure of several years flying on the BAe 146. These episodes in some cases led to nausea, headache and in some cases loss of balance.

One airline (Ansett Australia Airlines) had started an investigation into the rising number of complaints related to contaminated air and created an *'odour committee'* in 1991 to address concerns being raised by employees. This committee involved members of the Ansett Australia Pilots Association and Flight Attendants Association of Australia (FAAA) as well as a number of *'experts'*. While material was being gathered and many of the affected crew were transferred to other models, no real solutions emerged and a wider debate took some time to develop, although the industry as a whole was aware of the problem.

AFAP continued to receive more and more reports relating to contaminated air and discovered that the number of cabin crew being medically released from duties on the BAe 146 was increasing. [34] Then in July 1997 there was a significant flight safety incident onboard a freighter BAe 146 aircraft linked to contaminated air. [22]

The medical expertise that the Ansett Australia committee was relying upon seemed from the outset very determined to avoid investigating any other alternatives than specific accepted medical wisdom of the individuals involved. This point should be emphasized, as even during the later public submissions to the 1999-2000 Senate Inquiry, there were accusations still being made by the airlines to minimise any complaint as being related to stress, hyperventilation, hormone imbalance, or something related to being female. [43] The basic problem with the denial philosophies used was that the pilot involved in the 1997 incident was a fifty-year-old male who thought he was quite relaxed. [44,45,46]

These events triggered the union and author to take a more active interest in the issue and prompted development of an investigative survey of its members.

4.3.1 Methodology for the Health Surveys

In each of the three surveys, the organisation sponsoring the survey was a pilot trade union.

A survey questionnaire was developed that:

- collected respondent demographic information;
- collected information about flying history and experience;
- collected information about health status and health effects in flight crew;
- assured anonymity (so as to gain a more frank response by survey participants).

The survey was divided into five sections: demographics; flying history; flight deck events; health survey; and other comments. The first four sections collected specific data form answers to specific questions. The last section was an open-ended section that allowed participants to provide personal observations. A self-addressed return envelope was provided to increase the response rate.

The initial questionnaire was trialled with a number of pilots and staff from the AFAP head office at an informal meeting. Useful comments were received from this trial, and the questionnaire was revised prior to use. While this may not constitute a suitable validation process, the questionnaire was successful in collecting data, and with slight modifications, was successfully used in the other two surveys.

Ethics approval for the health surveys conducted in Australia was obtained from the UNSW Faculty of Science and Engineering Ethics Panel in 1999.

4.3.2 The 1999 AFAP BAe 146 Health Survey

Background

The first health survey was conducted in 1999. The survey was aimed at AFAP pilots who flew on the BAe 146, and although the questionnaire was sent to pilots who were members of the union, some flight attendants also replied.

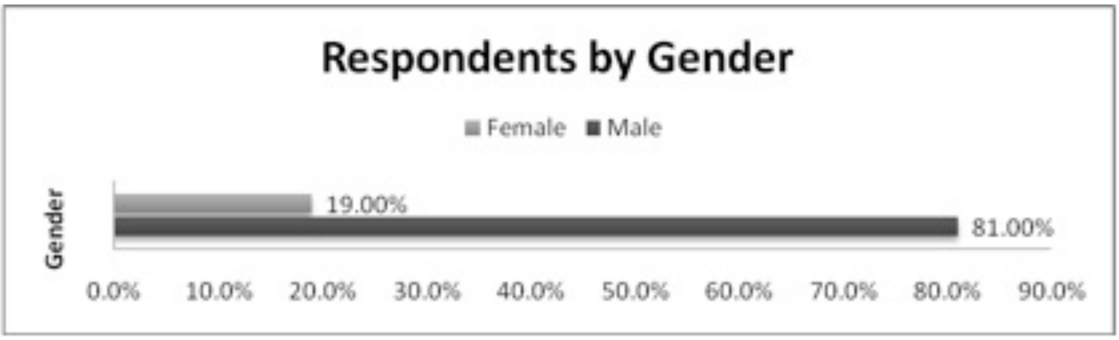
Informally, the union was informed that one airline discouraged its pilots from responding, to the extent that letters containing questionnaires were removed from individual pilot’s mailboxes, so that pilots only became aware of the survey after it had been completed. Ultimately, only 21 questionnares were returned. As it cannot be estimated how many pilots received the questionnaire, a response rate cannot be calculated. However, it can be concluded that the response rate was low.

Results

Demographics of respondents

The majority of pilots in commercial aviation are male. This was reflected in the results of the survey, in that the majority of crew (81%) who responded were male (see Figure 4-1).

Figure 4-1: Gender



Similarly, most respondents were in the 30-50 age group (see Figure 4-2).

Flying history

While the survey was targeted at flight crew, 90% of the respondents were pilots with a further 10% being flight attendants.

Of the respondents whose primary flying role was flying, the number of years flying is shown in Figure 4-3. All pilots were currently flying the BAe 146 full time (that is, they did not fly other models).

Figure 4-2: Respondents by age

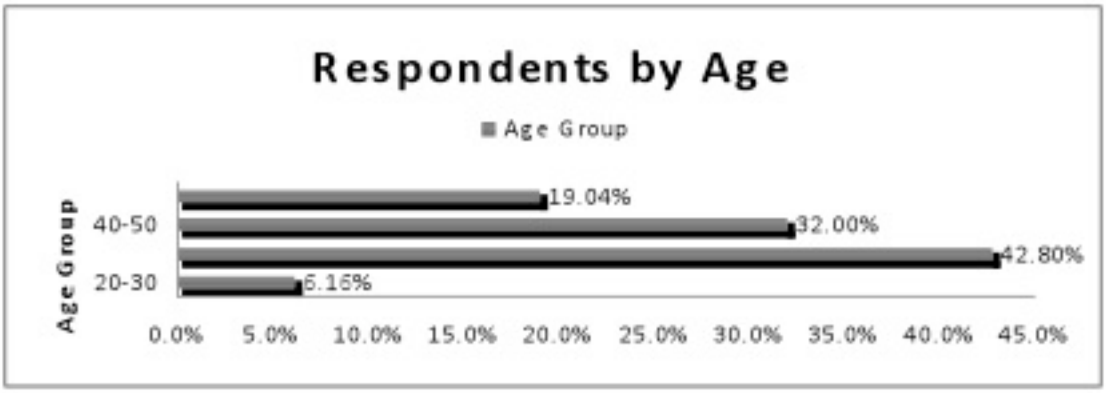
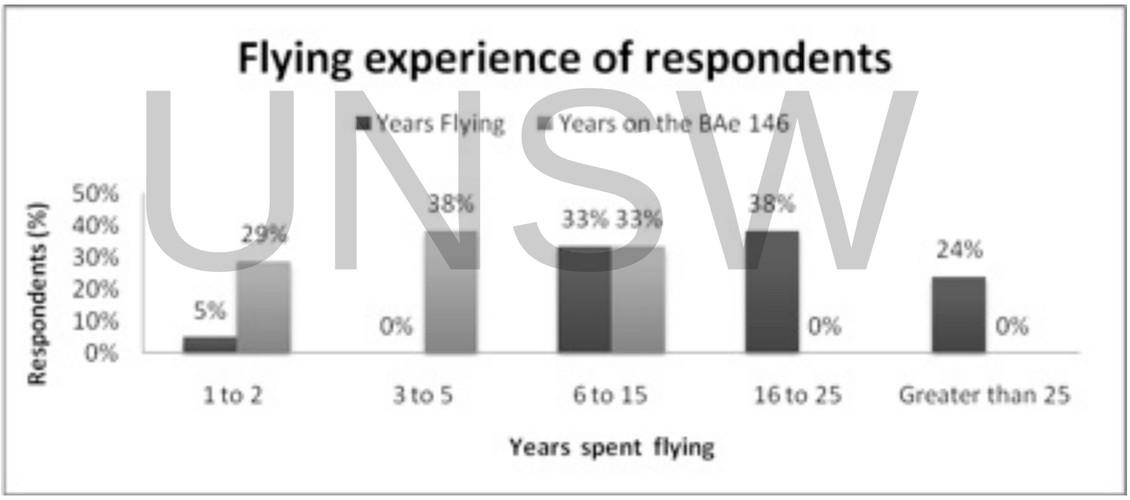


Figure 4-3: Flying experience of respondents



There was substantial flying experience with the respondents; although flying experience on the BAe 146 was less than total years flying. Further, all pilots noted that they flew more than 500 flight hours/year in their current positions.

Health survey responses

The questionnaire contained a number of questions about health problems, including a list of symptoms, duration of symptoms and the like.

Respondents were very positive about the quality of their health before flying, or before flying on the BAe 146 (see Table 4-2). Respondents were less positive about whether their health had suffered while flying on the BAe 146. Most considered that the number of symptoms had increased, that they were specific to flying on the BAe 146, and that the symptoms improved away from the plane (see Table 4-3)

Table 4-2: Health status

Health status	**Good**	**Moderate**	**No Answer**
How was your health prior to flying career?	95%	0%	5%
How was your health prior to flying BAe 146?	100%	0%	0%

Table 4-3: Symptom development

Symptoms	**Yes**	**No**	**No Answer**
Have symptoms increased since flying the 146?	95%	0%	5%
Do symptoms increase same amount on other models of planes?	0%	63%	37%
Do symptoms increase more on duty?	84%	5%	10%
Do symptoms increase more on BAe 146 than elsewhere?	68%	0%	32%
Do symptoms decrease a few hours after sign off?	63%	16%	21%
Do symptoms improve on holidays or days off?	90%	5%	5%
Did you have symptoms prior to flying BAe 146?	0%	95%	5%
Do symptoms only occur after exposure incidents?	47%	37%	16%

Just under half the respondents considered that the symptoms were associated with specific exposure situations, such as an engine oil leak. However, 37% did not, suggesting that they considered that symptoms were part of the normal processes of working on the plane. This finding is quite revealing, as it indicates a fairly widespread belief in the industry, that as well as the BAe 146 being a plane prone to engine oil leaks, there was a persisting residual problem not directly associated with specific leaks, but with a potential to continue to cause symptoms or affect health.

Data on symptoms were collected by asking the question: Do you experience any of the following symptoms during your work pattern? Respondents were asked to rate such symptoms as ‘Occasional’, ‘Sometimes’, ‘Often’ and ‘Long Term’. While the subjective nature of such ratings is acknowledged, they allow the respondent to answer the question in a manner that does not raise the problems that a requirement for quantitative answers may produce. Data on symptom severity is shown in Table 4-4.

Table 4-4: Symptom severity

Symptom severity	**No Answer**	**Occas-ional**	**Some-times**	**Often**	**Long-Term**
Headaches/light headed/dizziness	32%	21%	21%	10%	16%
Irritation: eyes, nose, throat	16%	16%	32%	16%	21%
Disorientation	74%	5%	5%	0%	16%
Memory impairment short-term	53%	10%	5%	5%	26%
Concentration difficulties/confusion	53%	16%	10%	0%	21%
Blurred vision, tunnel vision	90%	5%	0%	5%	0%
Nausea, vomiting, GI problems	90%	0%	0%	5%	5%
Fatigue, weakness, decrease performance	32%	21%	26%	0%	21%
Respiratory distress, difficulties	63%	0%	26%	0%	10%
Numbness (head, limbs, lips, fingers)	74%	5%	0%	10%	10%
Balance/coordination difficulties	74%	0%	16%	0%	10%
Joint pain/muscle weakness	84%	5%	5%	0%	5%
Intolerance to chemicals/odours	53%	5%	16%	0%	26%
Intolerance to foods/alcohol	84%	0%	0%	5%	10%
Skin irritations	79%	5%	16%	0%	0%
Immune system disorders	79%	0%	0%	0%	21%
General increase in feeling unwell	53%	5%	16%	5%	21%
Diarrhoea	90%	0%	5%	0%	5%
Cancer	100%				

Discussion

The data collated were significant as they revealed the most information available at the time about health problems associated with flying on the BAe 146. The following key points emerged from the survey:

- There was a wide range of symptoms reported, in many body systems;
- Some symptoms are reported at quite high rates (for example, headache or irritation or respiratory problems);
- Some symptoms occur quite commonly, such as skin irritation or disorientation;
- Some symptoms, such as coordination or memory effects present significant flight safety problems;
- Some symptoms only occur as long term effects (for example, immune system disorders).

The data show that the range of symptoms reported is quite extensive, and their frequency cannot be dismissed as being part of the normal health symptom background. Other symptoms, such as coordination or memory problems are alarming, bearing in mind the respondent is flying an aircraft.

Lastly, the questionnaire gave respondents *'white space'* to provide other comments. Some of these comments are noted below. In general, they supported the results of the survey data shown above, and are quite revealing in the additional problems they cover:

- *'Increased colds/running nose/watery eyes';*
- *'Increased skin irritation to eyes and neck'; 'Skin rash to hands';*
- *'On flights of 4 hours plus, extreme headaches usually occur next day and last for 24 hours';*
- *'Eyes become bloodshot and painful';*
- *'Violent protracted headaches';*
- *'Initial experience during duty or period immediately following, has now increased to approach to airport or similar environment';*

- *'Fatigue and lack of attention to detail has been evident for quite some time';*
- *'When PAC filters changed odour decreases';*
- *'Nausea felt whenever odour present';*
- *'Affect upon liver, fatigue, chemical sensitivity and sore eyes'.*

Conclusions

This study showed that the questionnaire developed for the survey was suitable to collect data for this type of study.

Overall, the survey provides limited data about health issues related to pilots flying on the BAe 146. It could be argued that the results of the survey should be dismissed, as they are not representative. However, the survey does provide self reported data from at least some pilots about health problems on the BAe 146.

The survey also confirmed the presence of contaminants in flight decks and passenger cabins of commercial jet aircraft and that such exposures constitute an air safety, occupational health and passenger health problem.

This part of the thesis was published as: Cox L and Michaelis S. A Survey of Health Symptoms in BAe 146 aircrew. *Journal of Occupational Health and Safety - Australia and New Zealand* 18: 305-312, 2002. [47]

4.3.3 The 2001 BALPA Short-haul Health Survey

Background

The 1999 AFAP survey was published in 2002. [47] As part of an increasing awareness that cabin fumes were a problem, other unions worldwide began exchanging information.

During this period, numerous reports were received by the British Airline Pilots Association (BALPA) from its members, confirming that they were experiencing exposures to contaminated air supplies whilst at work. The correct procedure for flight crew to follow after experiencing fumes in the flight deck was to fill in the aircraft maintenance technical log and, if it was felt that the incident as more than transient, to file an Air Safety Report (ASR). The airline then would decide whether to send the ASR to the UK Civil Aviation Authority (CAA) under the Mandatory Occurrence Reporting Scheme (MOR) — unless the captain had specifically requested this by ticking the MOR box on the ASR form. Data from the CAA clearly indicated that the number of reports received was significantly less than the number of incidents that the crew were experiencing. Therefore, it was decided by BALPA to carry out a survey of short-haul pilots within British Airways to determine the scale of the problem and to see if under-reporting of events was an issue in addition to looking at any health problems that may be occurring.

Since the earlier AFAP survey had shown a significant pattern of symptoms and that under-reporting was of concern, it was felt that a survey among BALPA members might show a similar pattern. BALPA in association with the author then undertook the health survey detailed below.

Methodology

The study population comprised all members of BALPA who were British Airways pilots on the Boeing 737, Boeing 757 and Airbus A320.

The survey questionnaire used in the first survey was modified and was divided into five sections: demographics; flying history; flight deck events; health survey; and other comments. The first four sections collected specific data form answers to specific questions. The last section was an open-ended section that allowed participants to provide personal observations.

Six hundred questionnaires were sent out to the survey population in October 2001. One hundred and six (18%) replies were received.

Results

Respondent flying history

The flying history of the respondents was: 1–2 years (n = 7); 3–5 years (n = 12); 6–15 years (n = 36); 16–25 years (n = 24); and 26+ years (n = 27).

Many pilots had a significant flying history, with nearly half of them having over 16 years experience.

Most respondents reported that they were flying the B757: not specified (n = 1); B737 (n = 2); B757 (n = 102); and A320 (n = 1). These data plainly show that most pilots flew on the B757.

Respondent demographics

Of the 106 respondents, 104 were male. Their ages were: 20–30 years (n = 18); 30–40 years (n = 40); 40–50 years (n = 25); and above 50 years (n = 23).

Respondent flying events

When asked whether they had ever experienced a smoke or fume smell during the flight deck event, 96 respondents replied *'Yes'*. When these 96 respondents were asked how many smoke or fume smells they had experienced, an estimated 1,674+ events were reported (with 1,667+ on the B757 from 93 respondents). By any standard, this is a large number of events.

There are clear criteria by which incidents involving the presence of contaminants in the cabin or aircraft must be reported. These are definable as defects or major defects. Few of these events were specified as events involving smoke: never (n = 74); occasionally (n = 19); sometimes (n = 6); often (n = 1); and no answer (n = 11). However, many involved fumes on the flight deck which were not associated with another aircraft in the vicinity: never (n = 3); occasionally (n = 42); sometimes (n = 34); often (n = 25); and no answer (n = 1). Of the 93 B757 respondents who reported a fumes event, 80 believed that the cause was oil contamination of the air supply system. Of the 93 B757 respondents who experienced fumes, 89 indicated that both pilots had smelt the fumes, with events lasting from a number of seconds to hours. A breakdown of these events is shown in Table 4-5.

Table 4-5: Details of flying events

Question	Response
How many smoke or fume smells on the flight deck events have you experienced?	96 respondents reported 1674 events
On which aircraft type did this/these occur?	1667 events were on the B757

Question	Response
What do you think, or what was the cause?	80/93 respondents believed cause was oil contamination of air system
How long were you exposed to abnormal fumes during each event?	Answers vary from seconds to up to four hours.
How would you describe each event?	Answers (covering the smell) include: • bad socks, banana smell, bitter taste, blueish mist, • funny smell, hot oil smell, insidious, nauseating, oily smell, plasticine type smell, sicky smell, smelly feet, taste of oil. Answers (covering symptoms) include: • bad smell, burning smell, dry throat, hazy smoke, head felt odd, headache, irritating nose, light headiness, metallic taste, splitting headache, stinging eyes, tingling skin, tunnel vision, visible fumes.
Did both pilots experience the event, fumes or smells?	89/93 respondents said both pilots experienced fumes (but a few commented that fumes were detected to different degrees of strength sometimes by pilots)
If you had an event, did you see or consider seeing your company doctor or GP? If not, what influenced your decision not to see a company doctor or your GP?	Most (90%) did not seek medical advice. Common statements for not seeking medical advice include: • individual felt better when in fresh air after event. • no perceivable ill effects. • event short so did not think it was a hazard. • ignorance. • felt better after fumes had cleared. • company doctor inaccessible or not available. • company doctor said symptoms were food poisoning so go home and rest. I was not convinced. • too tired to hang about for company doctor.

Question	Response
	• symptoms abated so I thought I was OK. • devotion to duty. • lack of ill effects. • known problem. • had another flight to do (commercial pressure). • told no need to worry about long term effects. • company said fumes had no long term health effects. • no tests available. • part of the job on the 757. • company health department said did not need to see a doctor. • unwilling to risk licence. • company doctors not to be trusted. • night stopping so only local doctors available. • events so common, I would be going to company doctor every tour!
If you saw a doctor or GP, what tests or advice was given?	Of the 10% who sought medical advice/tests, advice included: • go and rest. • effects fully reversible after fresh air exposure. • saw company nurse who asked if they felt OK and then sent them home, no tests done only names put in a log. • nothing to worry about. • haemoglobin test. • lung function test. • blood test. • blood pressure check. • no known ill effects from oil smell inhalation.

Question	Response
	• cholinesterase test – not done by company.
Did you use flight deck oxygen?	96 respondents said 'No'. Comments include: • 'only when really bad'. • crews appear to believe that short exposure events without visible fumes not worthy of using oxygen.
Did you report the event or file an ASR?	Of 1586 fume events on the B757, only 61 reported in ASR.

As noted above, a number of these findings were in contravention of company or CAA safety requirements. Soon after the survey, the airline took steps to remind its crew to always adhere to company and CAA procedures in relation to oxygen use. The Civil Aviation Authority has since issued advice for crew to use oxygen when fumes are present. The airline also took steps to phase out a specific engine model which seemed to be significantly more troublesome than a newer engine model.

These findings indicate that leak events are occurring and are being under-reported by pilots, symptoms reported may be impairing the pilot's ability to fly, safety procedures (such as using oxygen) are often being ignored, and the significance of leak events is poorly understood by company medical personnel and crew. This is a similar trend to the extensive under-reporting that was found in Australia by the Australian Senate Inquiry into the BAe 146 problem.

Respondent Health effects

The questionnaire contained a number of questions about health problems, including symptoms, duration of symptoms, and the like. Of the 106 respondents, 104 respondents noted that their health was good before they began flying (the other two gave no answer).

These data show that the range of symptoms is extensive, and their frequency cannot be dismissed as being part of the normal health symptom background. Other symptoms, such as fatigue, coordination or memory problems, may have additional significance to safety.

Pilots were also asked about whether their health had suffered while flying on the B757. Most considered that the symptoms occurred not only following specified leak events, often occurred on duty after leak events, and improved after duty or on days off (see Figure 4-4). Table 4-6 shows respondent answers to the question: 'Have you experienced any of the following symptoms during your work pattern?'

These symptoms are indicative of at least discomfort, fatigue, irritation and/or toxicity. Symptoms reported as being 'occasional' by at least 10 respondents include: irritation of the eyes, nose and throat (37%); headaches, light-headedness, dizziness (33%); fatigue, weakness, decreased performance (30%); general increase in feeling unwell (27%); concentration difficulties, confusion (21%); diarrhoea (16%); nausea, vomiting, gastrointestinal problems (15%); numbness (head, limbs, lips, fingers) (12%); short-term memory impairment (11%); and joint pain, muscle weakness (9%). High rates of eye, nose and throat irritation (59%); headaches, light-headedness and dizziness (52%); fatigue, weakness and decreased performance (53%); concentration difficulties and confusion (30%) and general increase in feeling unwell (39%) were noted to be occuring from occasional to long-term.

Of all the data collected in this survey, the symptom severity data reveal the most about health problems from flying on the B757, namely:

- a wide range of symptoms was reported, in many body systems;
- some symptoms were reported at quite moderate rates (for example, irritation, headaches and fatigue);
- some symptoms occurred quite frequently (for example, confusion, memory impairment, diarrhoea and nausea); and
- some symptoms, such as coordination, fatigue or memory effects, presented significant safety problems.

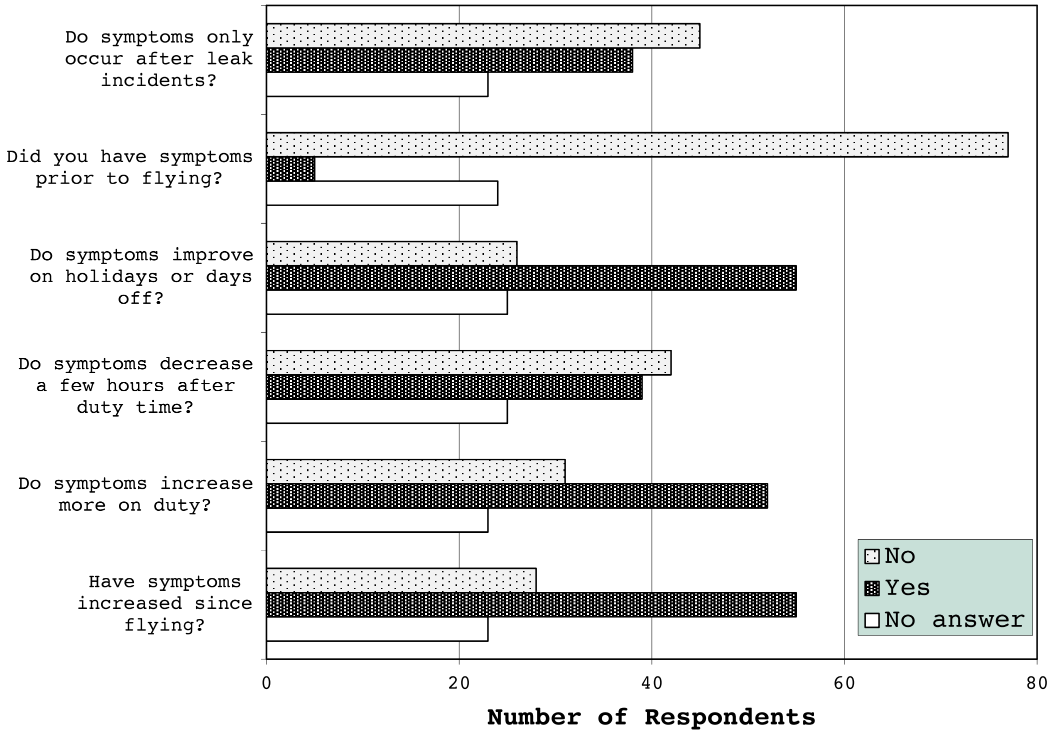
These data show that the range of symptoms is extensive, and their frequency cannot be dismissed as being part of the normal health symptom background. Other symptoms, such as fatigue, coordination or memory problems, may have additional significance to safety.

Pilots were also asked about whether their health had suffered while flying on the B757. Most considered that the symptoms occurred not only following specified leak events, often occurred on duty after leak events, and improved after duty or on days off (see Figure 4-4).

Table 4-6: Health effects in pilots (n = 106)

Symptom	No answer	Occas-ional	Some-times	Often	Long term	Never
Irritation: eyes, nose, throat	03	39	19	04	01	40
Blurred vision, tunnel vision	09	04	01	00	00	92
Respiratory distress, difficulties, change	10	04	02	00	01	89
Headaches/light headed/dizziness	04	35	15	03	02	47
Balance/coordination difficulties	10	03	02	00	00	91
Disorientation	12	09	03	00	00	82
Memory impairment, short-term	08	12	04	01	02	79
Numbness (head, limbs, lips, fingers)	05	13	03	01	00	84
Fatigue, weakness, decrease performance	07	32	18	05	01	43
Concentration difficulties/ confusion	07	22	07	02	01	67
Skin irritation	10	08	07	06	00	75
Nausea, vomiting, gastro-Intestinal problems	09	16	05	00	01	75
Diarrhoea	12	17	11	02	01	63
Joint pain/muscle weakness	09	10	05	01	00	81
General increase in feeling unwell	06	29	07	02	03	59
Immune system disorders	10	03	02	00	00	91
Intolerance to foods/ alcohol	10	04	04	01	02	85
Intolerance to chemicals/odors	10	04	11	01	00	80
Cancer (please state type)	2 - 1 Basal cell carcinoma and 1 Prostate					

Figure 4-4: Symptom incidence in pilots



Graph courtesy of The Journal of Occupational Health and Safety/CCH Australia Ltd.

These data suggest a substantial juxtaposition between occupation and effects.

Comments made under the section ‘other comments’ in the questionnaire included:

- *‘After my most noticeable occurrence, I experienced tingling in extremities for 24 hours, in addition to a feeling of lower than normal concentration and memory skills.’*
- *‘Company doctors cannot be trusted. This is too big.’*
- *‘Captain had degraded attention and I could not allow him to fly the approach or landing.’*
- *‘How much did my company know about this but chose not to mention?’*
- *‘I feel that, as a regular reporter of fumes on the flight deck, engineering is not taking my reports seriously as I am a regular complainer.’*
- *‘My worst experience was when I was asked to report further on oily smells on the flight deck. On return to my departure airport — because*

they were so bad and because we both felt ill - I grounded the aircraft (Report and ASR).'

- *'I don't think the company is doing nearly enough to resolve the obvious problem on the B757. The engineering department certainly appears unsympathetic.*
- *It is my impression that hot oil smells during take-off and the first few minutes have recently become a much more regular event on the B757s. Of 20+ events, most have been in the last year.'*
- *'First time on I was on the B757, the smell was not so prevalent, second time, much more often.'*
- *'I am now on the B737, partly because of the fumes, and now feel much better.'*
- *'Long-term feeling of fatigue.'*
- *'I reckon that every 3rd or 4th sector on the B757 I can detect oil vapour.'*
- *'I am concerned that I may have suffered long-term/permanent damage.'*
- *'When reported, I was told unless you use oxygen nothing will be done.'*

Discussion

Overall, the survey provided information about flying and health issues for BALPA pilots flying on (mainly) the B757:

The oils used in aircraft engines contain toxic ingredients, which can cause irritation, sensitisation and neurotoxicity. [13] This does not present a risk to crew or passengers as long as the oil stays in the engine. However, if the oil leaks out of the engine, it may enter the air conditioning system and cabin air. This is a direct contravention of the US Federal Aviation Authority's (FAR 25.831) and other similar airworthiness standards for aircraft ventilation which state:

- *'(a) Each passenger and crew compartment must be ventilated and each crew compartment must have enough fresh air (but not less than 10 cubic ft per minute per crew member) to enable crew members to perform their duties without undue discomfort or fatigue.*

- *(b) Crew and passenger compartment air must be free from harmful or hazardous concentrations of gases or vapours.'*

This study has shown that contamination of the cabin and flight deck air supply causes toxic exposures to, and adverse health effects in, flight crew (on the flight deck, these fume events are sometimes producing effects in both pilots). [34,48]

Although there is a perception by aircraft manufacturers, regulators and airline operators that *'a little bit of contamination'* should not be regarded as an operational problem, this problem should at least be defined as a defect (as required under the aviation regulations).

The findings of the present survey are consistent with other studies previously published on this issue, including a study undertaken by the author on health symptoms reported by Australian BAe 146 pilots. [19,21,28,47] Both the BAe 146 pilots and the B757 pilots reported a similar pattern of extensive symptoms at high to moderate rates (including eye, nose and throat irritation, headaches and dizziness, fatigue, feelings of being unwell, concentration difficulties, memory impairment and nausea), although the symptoms were at a higher frequency and with more long-term effects among the BAe 146 pilots. In addition, symptoms occurred not only after specified leak events but also during 'non-event' flights, and were more prevalent on the B757 and BAe 146 than other aircraft.

Residual contamination (as well as specified leak events) may be causing problems.

There is a lack of understanding by pilots regarding the toxicity of the oil leaks, the health effects on OHS and the necessity to use oxygen. This is further compounded by the airline health professionals who, when confronted with a pilot who has been exposed in a fume event and who is concerned about its consequences, have a poor understanding of the short and long-term medical issues that may arise.

Pilots continue to fly when experiencing discomfort or symptoms.

Conclusions

The findings of this survey (including the number of crew reporting fume events, the number of fume events themselves, and the relatively high correlation of some groups of symptoms) suggest that, at least for the B757, this is a problem that requires further attention by the aviation industry.

Pilot exposure to contaminated air that causes discomfort or symptoms such as irritation, headache or fatigue is a clear contravention of the airworthiness regulation FAR 25.831, which includes a specific requirement that cabin air should not cause symptoms of discomfort, fatigue, irritation or toxicity.

Contaminants in the air of an occupational environment should, under normal circumstances, alert management to a potential problem. Proper medical and scientific research needs to be undertaken in order to help airline management and crew to better understand both the short-term and long-term medical effects of being subjected to air contamination.

This part of the thesis was published as: Michaelis S. (2003) A Survey of Health Symptoms in BALPA Boeing 757 Pilots, Journal of Occupational Health and Safety, Aust & NZNZ --19(3), 253-261. June 2003. [49] In 2002 the CAA advised BALPA that upon reviewing the B757 BALPA survey, the results were *'consistent'* with the CAA's understanding of the nature and scale of the issue. [50] The CAA CMO (now ICAO CMO) advised that the survey confirmed there was a *'real problem on the 757'* that warranted continued industry research of oil contamination of the air supply and that there was no *'specific set of symptoms associated with reported smoke/fume events.'* [50]

4.3.4 The 2009 UK BAe 146 /146 RJ Pilot Survey

Introduction

BALPA had been concerned about cabin air contamination for many years and the inaction by the aviation industry to address the health and safety issues. [51] Therefore in 2004 BALPA requested that the UK CAA assist it in examining ill health amongst aircrew related to contaminated air. [52,53,54] The CAA in conjunction with the Aircraft Health Working Group (AHWG) chose to examine the issues raised by passing the matter onto the UK COT committee and, as this solution did not involve collation of any crew data nor did it allow the collegiate collection of data between the industry and one of its unions, BALPA identified the need to commence gathering the data itself. [55,56,57,58]

There is an inherent problem already identified in getting pilots to report fume events, owing to a perception that pilots reporting such events would be highlighting potential health and safety implications contrary to safe flight and standard flight procedures and potentially in conflict with maintaining valid medical certification. Highlighting such problems could potentially lead to being adversely targeted by their employers or even intimidated by work colleagues. It was therefore considered that requesting data by asking pilots to speak out about adverse health and safety effects experienced in flight, which may be associated with possible exposure to contaminated air was problematic, particularly as the issue was raising more industry attention and controversy as the years went on. The CAA had clearly advised it was not willing to assist with conducting a BAe 146 health survey research as a cancer mortality study being undertaken for the CAA had not revealed any BAe 146 health problems and pilot sensitivities with medical studies and surveys had previously triggered adverse reactions from the pilot community, along with confidentiality requirements. [55] Additionally the CAA felt it was more appropriate to first determine if air monitoring studies revealed any *'conceivable risk to health'* based on chemicals found and if so, studies should be undertaken by an organization with a *'reputable track record in scientific investigation in order that the results would stand up to peer scrutiny',* which was according to the CAA supported by some within BALPA. [55] The CAA believed that such work should be overseen by the AHWG.

However the BALPA National Executive Council (NEC) and BALPA Aircraft Environment Task Group (AETG) decided the survey should proceed. Consequently, following on from the BALPA 2001 B757 health survey and the 1999 Australian BAe 146 health survey, [47,49] it was determined that as the BALPA pilots flying the BAe 146 (as shown in Figure 4-5) and RJ fleet were reporting in flight exposures it was deemed a suitable fleet to survey. [59]

Given the industry ongoing and increasing resistance to the issue, the failure of the airlines and regulator to effectively educate the pilots appropriately of the possible risks with exposure to contaminated air; it was apparent from the outset that gathering the data may be difficult.

Figure 4-5: BAe 146

For pilots to admit they may have had some form of impairment in flight or ongoing health issues is an airworthiness issue and contrary to the aviation regulations, necessitating both reporting and possible suspension of the pilot's medical licence to fly and possibly, cessation of employment. However in reality, the CAA medical unit and CAA approved doctors upon being advised by pilots of contaminated air exposures and effects reportedly failed to take any interest in the matter. Additionally BALPA AETG members were informed by CAA doctors that that the CAA was only interested in medical certification and fitness to fly at a given time and oil contamination effects did not fall into the area of immediate licensing certification.

It must be noted that without a mandatory survey (which would likely be not reported accurately for reasons given), an unprompted style was not possible. The BALPA and the Independent Pilot's Union (IPA) cabin air contamination campaigns helped validate the need for the survey and the fact that it was being undertaken by pilots who were known to be very involved in researching the issue that enabled trust to be established and some pilots becoming willing to talk. The author believes that crews would not easily divulge information to an outside authority or the aviation regulator for reasons stated.

It is well recognised that pilots are reluctant to divulge information about their medical conditions or adverse health for fear it may jeopardise their medical certification. This is a very important aspect as it clearly identifies major limitations in trying to get a true understanding of the scale of any problem that may impact on health, employment and of course flight safety. In 1986, the US FAA noted that *'for occupational/economic reasons'*, pilots were *'less likely to voluntarily remove themselves from follow up observation for known medical conditions that would preclude FAA medical certification'*. [60] The FAA also noted that pilots should be educated to report history or symptoms of any disease during periodic medical examinations. A USAF report noted an important limitation in trying to assess ill health, with the limitation being *'acquiring complete and accurate medical information from pilots with a profession, hobby or aircraft investment to protect'*. [61,62] This was also clearly recognised by pilot unions, doctors [34,45, 63] and the UK Government in 2009 when asked about undertaking a pilot health survey when stating *'We are also aware that it could be difficult to recruit pilots, who in the UK would be legally obliged to report any health impairments found (related or not to cabin air) to the CAA who licenses them.'* [64]

The survey was initated by the BALPA AETG but after it was disbanded, its former Chairman Tristan Loraine helped set up the much larger Global Cabin Air Quality Executive (GCAQE) and the author who was appointed Head of Research for the GCAQE enabling the work to be concluded with the support of the IPA.

The survey could be criticised for not following the rigourous procedural protocols of conventional questionnaire based studies. However given the unwillingness of the UK CAA and airlines to assist in advising who could be contacted, a lack of financial support from either unions, regulators or airlines and the very noticeable resistance to discussing the issue, even later on within the pilot union BALPA, the data that are available is the first of its kind and reveals important information. This is particularly critical given the implications for flight safety; the recognition that oil contamination was occurring within the

BAe 146/RJ fleet; the ongoing significant contaminated air reporting database [65] showing that under-reporting was occurring; reports showing considerable crew impairment and of course the implications for crew and passenger health.

Methodology

The survey was initially conducted in the UK at the direction of BALPA commencing in 2005. Given that the author had conducted the previous BAe 146 and BALPA B757 surveys, the author was initially requested by BALPA AETG Chairman to act as an unpaid consultant and subsequently as an unpaid research officer for the present survey. The author as the unpaid Head of Research of the GCAQE, continued the work after the cessation of the BALPA AETG. The non self selected quantitative survey population comprised former and current BAe 146/146 RJ UK pilot licence holders.

While the survey was conducted in the UK, it was deemed that UNSW ethics approval was not required, however given that the author who had been centrally involved in the surveys from 1999 onwards, the original UNSW ethics approval format was adhered to.

Recruitment of respondents

Recruitment of respondents was initially very difficult, owing to reluctance of the regulator, airlines and some pilots themselves to support the research. Later, as pilots became aware of this issue through widespread union based information campaigns, recruitment of pilots became much easier.

As the UK CAA was unwilling to identify the number of past and present pilots in the UK who had flown the BAe 146 or BAe 146 RJ, the only means to determine who had flown the aircraft was through the pilot unions and its members. BALPA membership and certain BALPA and IPA members provided a limited list of crews who had flown or who were still flying on the BAe 146. Significant support was received from the Independent Pilots Association who provided details of their members who had flown the aircraft and old pilot seniority lists from several UK airlines, which enabled the author to find further names of crews who were flying or who had flown the BAe 146. Old seniority lists were also obtained from crews who had been employed at Dan Air and Air UK, two former BAe 146 operators.

Given the refusal by the UK CAA to assist with contact details, many pilots who had flown the BAe 146/ 146 RJ remained uncontactable. 2002 [66] pilots in the UK have been licensed to fly this aircraft at some stage of which only 274 (approximately 14%) were available to participate in the study, out of a list of 389 pilots whose names (but not necessarily contact details) were known by the author to have flown the aircraft type in the UK. The 2002 figure will include non UK resident crews who may have trained in the UK and who obtained a UK CAA BAe 146/146 RJ type rating, but who did not necessarily fly the aircraft for a UK operator, as well as deceased pilots.

However, in a few cases where another pilot was in a documented major event with a *'non contactable'* pilot, the data were recorded at the discretion of the author. Although it took considerable time, the number of contacts increased over time as crews provided contact details of additional crews who they were aware had also flown the BAe 146 or RJ. While the sample size may be small, it was the best that could be collected without Regulator and Government support. Additionally, the resistance of current pilots in divulging information cannot be understated, and as such the information must not be discarded. Further, what did emerge as data collection progressed is that bleed air contamination was occurring more than was reported, and the early findings appeared to mirror the data previously collected.

Collection of questionnaire data

Initially, the request for data was conducted by sending out a written questionnaire. It soon became apparent that there was unwillingness for crews to answer such sensitive matters in a written format. Additionally, the address database was not very robust, so trained individuals from the AETG carried out telephone interviews using the questionnaire form. Calls were sometimes followed up with email requests for further information. The crews were asked which model of aircraft they had flown; for which airline; over what period; and whether they were aware of the BALPA or IPA contaminated air campaigns. They were additionally asked if they had ever noticed contaminated air on the aircraft and if so how they described it and how often. The respondents were asked if they had experienced any symptoms, either immediately or soon after exposure or sometime after exposure. Very few respondents were provided sample symptoms unless they specifically asked for clarification as to what type of symptoms might be relevant. The respondents were then asked if they were aware of other crew who had reported ill effects associated with cabin air and for any other information considered relevant.

Based on the telephone survey format, it was soon noted that there was a wide variation in the degree of information sought from the respondents, given the fact that few in the pilot union were really equipped to discuss the issue in detail and most of those conducting the interviews found there was resistance to discussing the issue with their own colleagues, given the possible repercussions from within their own companies.

However, by mid 2005, initial results appeared to be significant. The author had been consulted on the survey format and design and had been closely observing the progress of the survey from the outset, and was responsible for collating the data being collected by BALPA air quality representatives. It was considered that the data, to that point, warranted a more significant effort. The same trained interviewers were utilised, however a more indepth approach to data collection was introduced. The list of questions was formalised, and rather than conduct a free-flowing interview, these questions were read out to the interviewee over the phone and their answers recorded. In a few cases, the questionnaire was forwarded to respondents by email. Additionally interviewers highlighted to crews the correct procedures for reporting cabin air quality events and the need to adhere to checklists and FODCOM guidance in realtion to contaminated air exposures.

In 2004 BALPA sent all its members a copy of the AOPIS documentary made for the Australian pilot union AFAP [67] and in 2005 BALPA sent out a contaminated air awareness brochure and later requested any pilots reporting effects soon after exposure to contact them. [68] In 2008 the IPA sent all its members the 2007 documentary ‘Welcome Aboard Toxic Airlines’ to aid in its process.

With greater awareness about the contaminated air issue in the pilot community and less BALPA involvement from 2006 onwards, it seemed there was some increased willingness to discuss the effects as time went on. Consequently, after the GCAQE had started to support the research in 2006, it was decided that the formal questionnaire should be sent to those new individuals willing to participate and to those for whom more information was thought to be required, something, which due to a lack of resources, had never been able to be conducted previously. Given the overall increased willingness to discuss the matter by late 2006, the author, as the Head of Research for the GCAQE, directly took over the survey collection of data.

It became very noticeable that pilots within some companies were far less willing to participate than others. In part, this was due to the input from the union representative for that particular company. Crews that were unsuccessfully contacted were continuously selected on a repeated basis to try to be contacted and conduct the survey. In the latter period of data collection, a different, more comprehensive survey form was used to determine if there was a difference in reporting patterns with a more comprehensive questionnaire utilised. It was clearly demonstrated straight away that the final more comprehensive questionnaire using onset and duration of symptoms was far more effective at yielding results.

As noted above, a two phase process emerged, where the first phase was contact of a prospective pilot with an experienced trained BALPA pilot to discuss issues and establish trust. If the prospective pilot agreed to take part in the survey, he or she was contacted again in the second phase, and information collected using a questionnaire modified from the two earlier studies.

The aim of the survey that ultimately took place over four years (2005-2009) was to determine the exposure history and any identify health effects to determine if they fitted a specific pattern. While it was assumed there would be a high rate of awareness of the general contaminated air issue onboard the BAe 146, it was known that many crews did not necessarily link exposures to specific health effects. This was especially critical and beneficial to the process of data capture and ensured the data collector did not lead the respondent.

Data analysis

The data collected from the questionnaires and interviews was recorded on a Microsoft Excel spreadsheet. Given the difficulties in reporting, statistical analysis was not conducted on this survey. The data were then analysed using

Microsoft Excel and downloaded to Microsoft Word for graphical purposes. Qualitative open-ended responses were recorded. The analysis does not differentiate between questionnaire or interview data.

All data were collected on a confidential basis, then deidentified once added to the database and stored on a password protected system. The original material is property of the author and is stored in a secure safe system and will be destroyed on completion of the thesis.

Results

Demographic Characteristics

Figure 4-6 shows the basic demographic breakdown of those past and present BAe 146/RJ crew in the database, those successfully contacted and the gender breakdown.

389 past and present BAe 146 and or BAe 146/RJ pilots were collated in the database. Of these, 274 (70%) were contactable.

Of those in the database 94% (366) were male, while 6% (23) were female. Of those contacted successfully 93% (254) were male and 7% (20) were female. The female contact ratio based on the available database was 87% (20), whilst it was 69% (254) for male pilots.

Flying experience and years flown

Where available, data were collected on the airline and specific model flown. In some cases crews had flown both models or only commented on their current type. It was found there was greater resistance to participation from former and current British Aerospace pilots, management pilots within UK airlines and pilots working for freight carriers. Surveys were undertaken of pilots on both model aircraft and exposure awareness and impairment was noted for both models. Figure 4-7 shows the flying experience reported by the interviewees.

The largest number of respondents at 29% reported flying the aircraft between 3 and 5 years, while 25% flew the aircraft for 6-10 years. 19% of respondents flew the aircraft 11 or more years. A significant number of those reporting flying the aircraft over 11 years in fact reported 14-18 years on the aircraft with the maximum noted at 22 years.

Figure 4-6: Numbers contacted

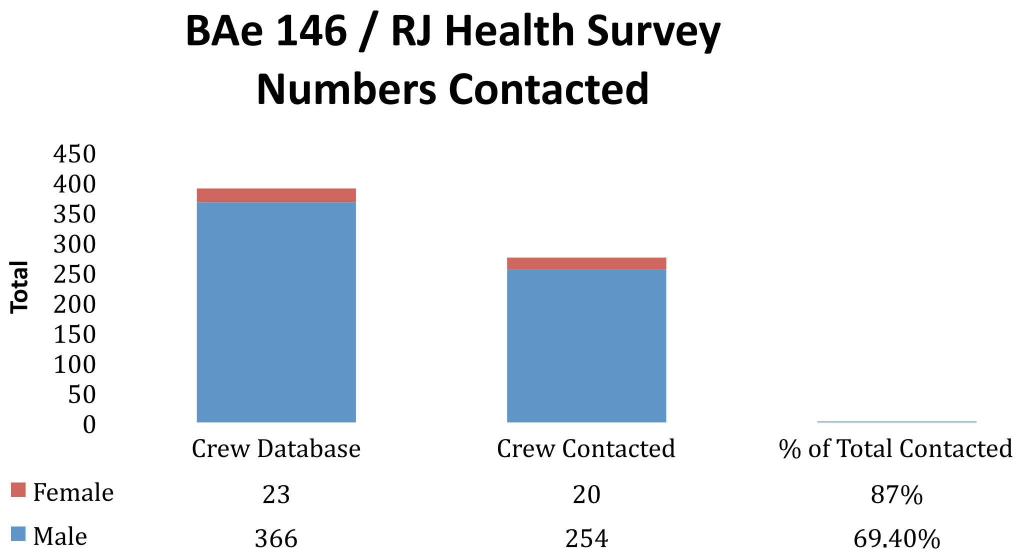
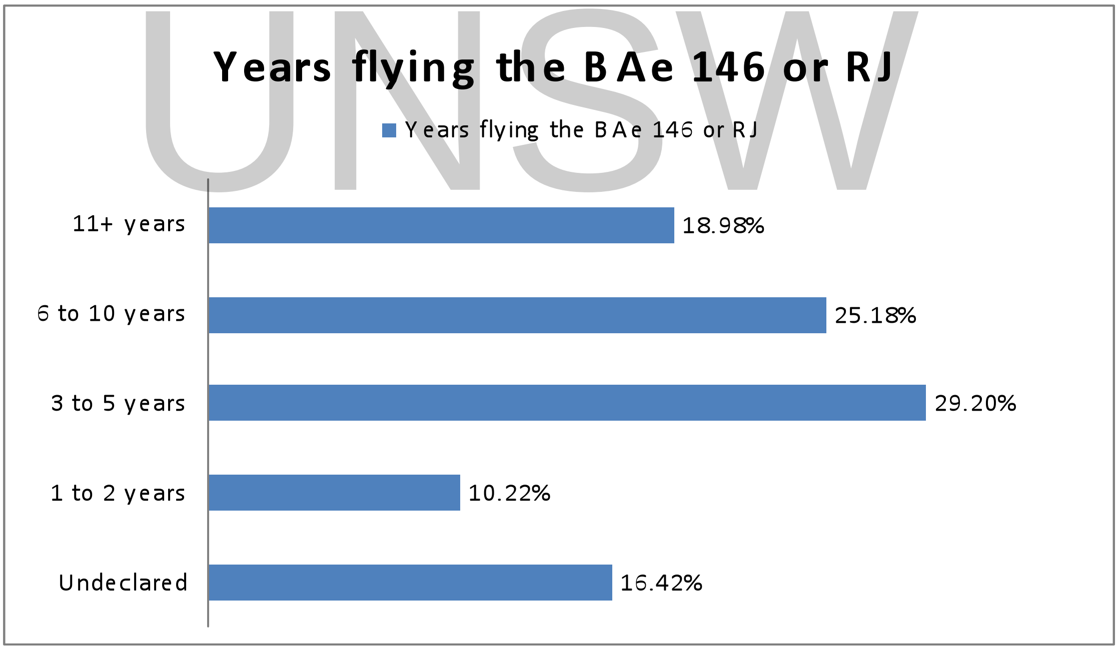


Figure 4-7: Years flying on the BAe 146 or 146 RJ

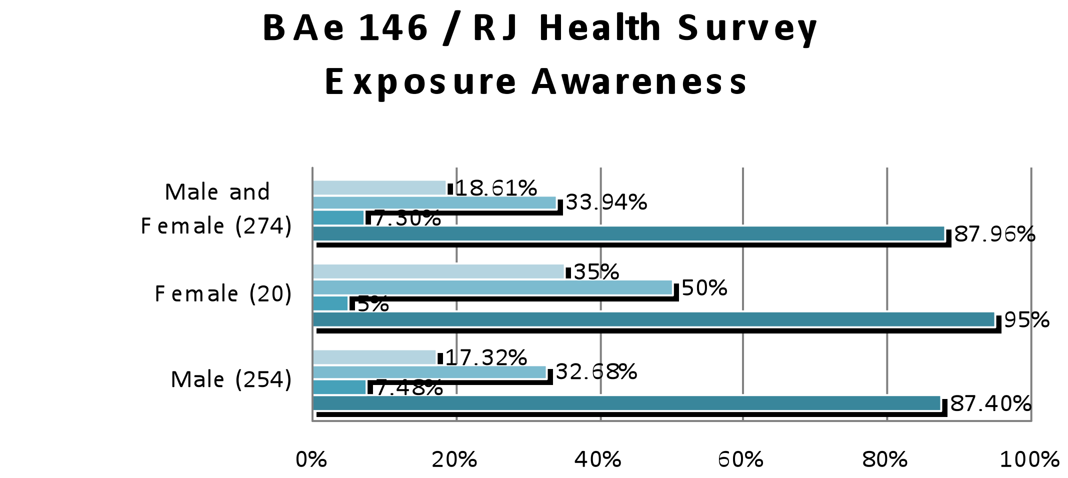


The length of total flying experience was often given but not consistently recorded, so it was not tabulated. However, it was often significant.

Exposure awareness

Figure 4-8 identifies crew awareness of exposure history. 88% (241) of those contacted advised they had been exposed to contaminated air. While the majority was identified as oil related, there were a few reports of exposure to hydraulic fumes and deicing fluid fumes. 95% of the females contacted advised awareness of the contaminated air while the rate was 87% for the males. 91% of all those contacted were aware of the cabin air contamination issue.

Figure 4-8: Exposure awareness



	Male (254)	Female (20)	Male and Female (274)
1 or 2 big events	17.32%	35%	18.61%
Frequent or repeatedly exposed	32.68%	50%	33.94%
Visible smoke or mist	7.48%	5%	7.30%
Exposed	87.40%	95%	87.96%

The contaminated air events were often described as dirty socks, oil fumes, oily odour, chemical smell, wet dog, vomit and similar. Further information was dependant on the questions asked by the interviewer and or the willingness of the respondent to talk or provide information. In many cases, little further data were given. Visible smoke or mist was reported by 7% of those contacted, frequent or repeated exposure in 33% of cases and 19% of respondents stated they had experienced one or two significant events. In some cases, crews would report they had experienced all three of these scenarios. It is thought this information was incomplete as it relied on the respondent to volunteer these data.

Contributing factors

As stated, the respondents were aware that the database was being collated as part of a review into contaminated air and possible health effects. There is little doubt that there was a high awareness of this, however the interviewers and questionnaires still left it to the respondent to explain what they thought might have contributed to their symptoms. While a large number assumed there was a connection between symptoms and exposure, a number did not make such a positive connection, either because they felt there wasn't a link or due to limited knowledge of the issue and the diverse possible consequences of exposure. However, in the later case, the exposure history and symptomology were strongly present. Additionally the term fume or contaminated air event was generally used and technically covered gases and vapours as well as particulates in the form of mists, fumes, mists or aerosols.

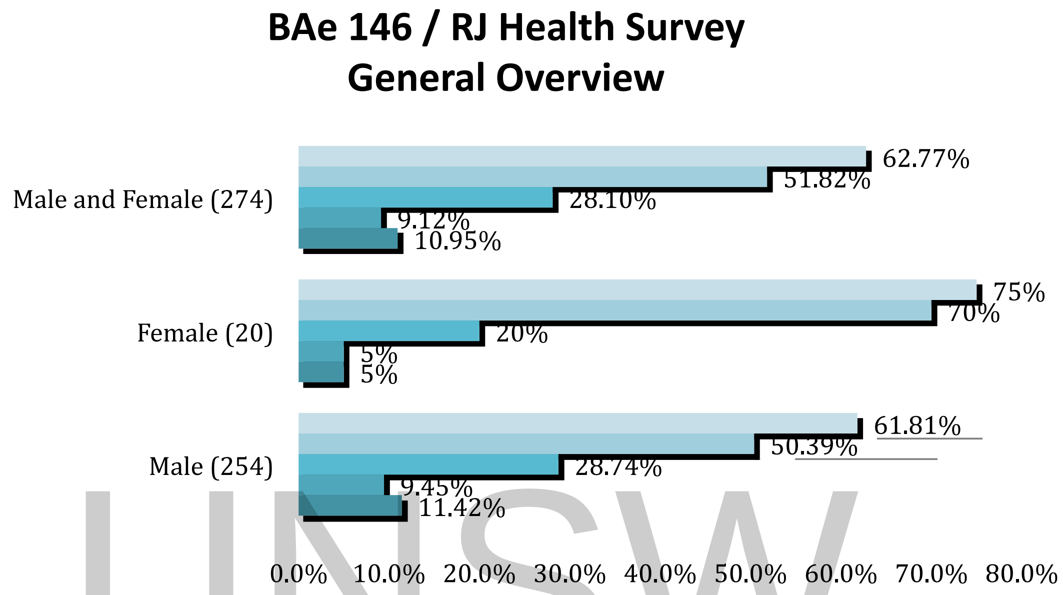
As it is not possible to graphically describe the positive connection between exposure and effects by the use of statistics and graphs, examples of the association are listed below:

- *'I can remember the terrible smell of what we called "sweaty socks" every time we got in one. (BAe 146) …the Captain I was with at the time told me the way to get rid of the smell was to turn the heating up. Standard practice apparently! ...by the end of the week I was hardly able to walk as I was having trouble breathing. I managed to get the plane to LHR to help the company out as they had no-one else and then spent the next 7 weeks off with a very bad attack of double pneumonia... Range of symptoms ongoing for next 13 years. Medical removed by CAA 17 yrs later: Still has severe cough. The tremor in right hand is now much worse/severe.'*
- *'Exposed regularly from 1990 till 2006. Several big events: confusion, brain fog, slurred speech and poor word finding, bad memory, feeling of intoxication...'*

Symptom onset

88% of crews contacted reported a confirmed exposure history to contaminated air with 63% of the respondents reporting adverse health effects as shown in Figure 4-9.

Figure 4-9: BAe 146/146 RJ health effects reporting overview



	Male (254)	Female (20)	Male and Female (274)
Total Health Effects	61.81%	75%	62.77%
Specific Health Effects Declared	50.39%	70%	51.82%
No Reported Health Effects	28.74%	20%	28.10%
Health Effects Unknown	9.45%	5%	9.12%
Symptoms 'Yes' but not declared	11.42%	5%	10.95%

Specific declared health effects were reported by 52% (142) of those contacted, with a further 11% (30) reporting they had experienced adverse effects but did not identify them. Heath effects were unknown in 9% (25) of crews while 28% (77) advised they had not experienced any adverse health effects that might be related to their flying environment or exposure to contaminated air.

While the population of females was far smaller, there was a slightly higher ratio of those reporting adverse effects at 75% compared to 62 % for the males. As a percentage, the females were a little more willing to divulge health effects at

70% of those contacted, while males reported specific effects at 50%. The males were slightly more likely to report no health effects.

It is expected that in all these figures bar the *'no health effects'* will be understated, given the reluctance of crews being willing to discuss these matters, or matters in detail. It was often noted that those reporting they had no effects would indicate neither did any of their colleagues, when the interviewers had often spoken with their colleagues or recorded fume events when interviewing their colleagues where effects were reported. Of those reporting *'no awareness of the fumes'* and generally *'no effects'*, apart from those genuinely who had no sense of smell (2% of the community), [69] it was noted that this was unlikely given the high level of publicity about the issue (from unions, manufacturer, regulator, airlines) and the strong awareness reported by their colleagues. In fact, based on industry and airline documentation supplied to BAe 146 pilots, all pilots would be required to know the problem was going on, impairment and incapacitation had occurred and selected actions were mandatory. However, this would not be the case if the crew were not reading the required documentation or it was not being passed on to them or there were conflicting messages of what constituted a *'fume event'*, which has been documented by the author and in official reports.

Figure 4-10 and Figure 4-11 both show the onset of symptoms in further detail. With reported 88% exposure rate to contaminated air, 63% reported adverse health effects of some sort, ranging from immediate through short-term, medium term to long-term effects. These were assessed at:

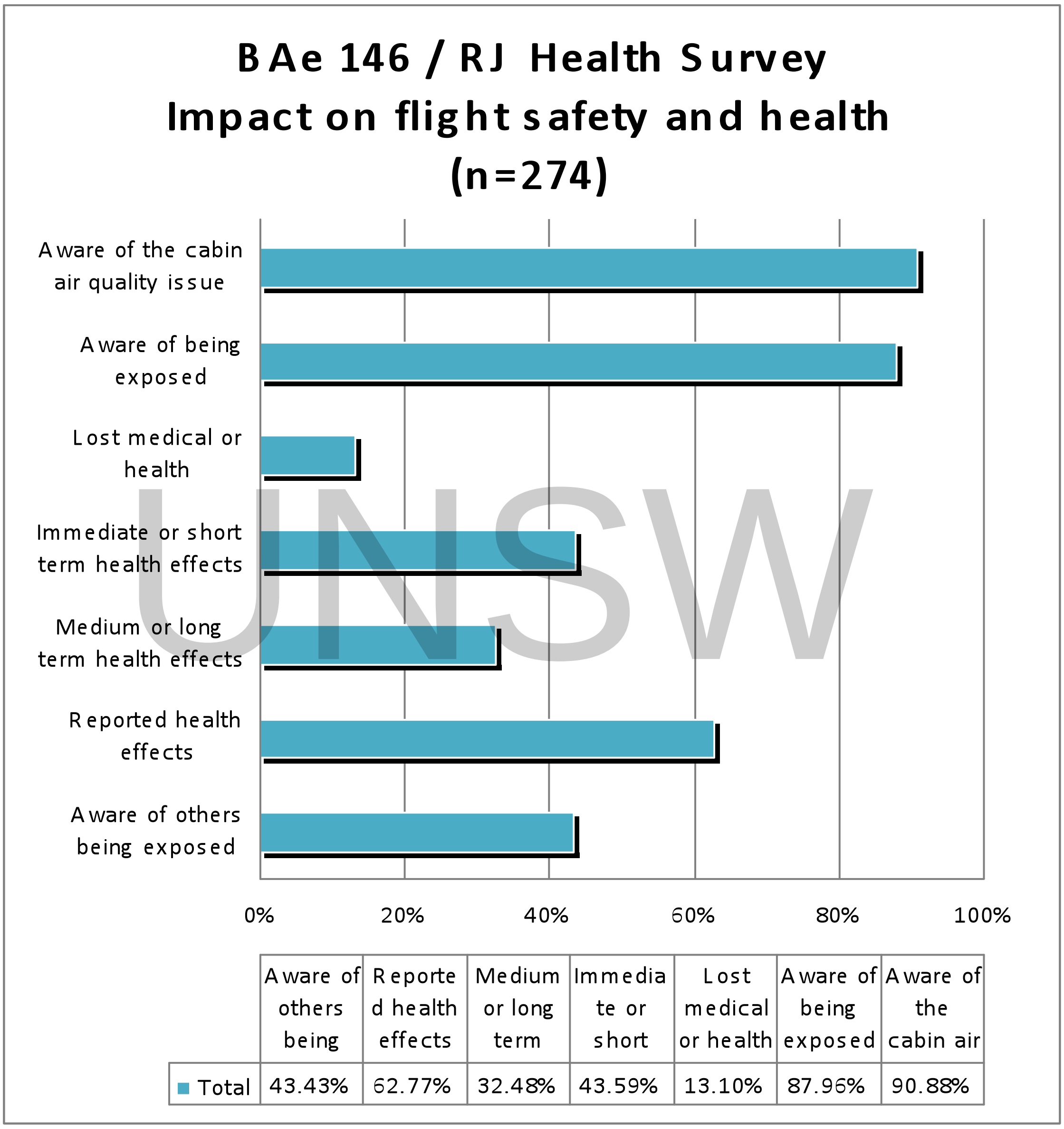
- short term - as days to weeks;
- medium term - weeks to six months; and
- long-term - six months or longer.

Figure 4-11 provides a breakdown of males and females; however it is considered that the population of females was too small to provide meaningful data with data available supporting overall consistent health effects between male and females.

Immediate or short term effects

44% (120) of those contacted reported immediate or short-term adverse health effects (Figure 4-10) immediately after or shortly after exposure to contaminated air.

Figure 4-10: BAe 146/146 RJ Health effects and impact on flight safety



This is clearly a major flight safety issue that should not be ignored and has been identified many times over the years, including by British Aerospace who stated that oil fumes should be considered a flight safety hazard. [70] The majority of crews failed to use oxygen during contaminated air events, [65] despite the advice since at least 2000 to do so. In a few cases the crews were sent to hospital, however this was infrequent and the data were not actively collated.

The majority of crews took no action during or after fume events apart from taking time to recover. This is consistent with previously identified trends where fumes were seen as normal and part of the job, with little that could be done. [35,65] Supportive statements include the following:

- *'On stand I felt a little sick and just holding short of RW XX I felt very sick but I knew once lined up I would be better, I had got used to this on this aircraft on windy days but I alway coped with it and felt it was just an old oily aircraft. On the final flight the following happened, my hand went numb and I partially lost my speech which is one of the most alarming experiences I have had flying, the Captain couldn't understand why I could not take about three calls at the end of the flight. It is hard to explain, the words were in my brain but I could not get the words out it was as though my speech was disconnected from my brain. I had to get out of the aircraft in to the fresh air on arrival I felt so ill';*
- *'Recently xxx has been getting terrible headaches and being sick but only when flying. After visits to the doctor, the CAA were contacted with medical withdrawn due to suspicions of organophosphate poisoning';*
- *'Suffers from nausea and sickness for up to 6 hours after flying and many colleagues are also affected';*
- *'I did experience some fume events, mostly irritation in the back of the throat and eye sensitivity. My experience was more feeling than smelling – We did all accept it, reluctantly, as no-one had any realistic solution at the time.'*

Previous studies (UK Contaminated Air Events Database – UKCAED [65]) examining the rates of contaminated air events have recorded that 34% of crew (pilots and cabin crew) reported some form of impairment during flight. The database shows at least one pilot reported impairment of some degree in flight during 20% of flights and that both pilots reported impairment during 9% of the recorded flights respectively. [65] However the UKCAED database was not designed to collate health information and will certainly have underestimated adverse effects related to flight. Therefore as shown in Figure 4-10, data shows that 44% of pilots reporting adverse effects immediately or shortly after flight is seen as a further important source of data on impairment in flight or soon after flight with significant implications for flight safety. The addition of cabin crew impairment would significantly elevate this figure.

Medium or long-term effects

Figure 4-11 reviews reported medium to long-term effects in BAe 146 crew. 32% of those contacted reported medium or long-term health effects that they either related to the cabin air exposures or which fell into a pattern of reported effects that are identifiable with exposure to contaminated air as shown in Figure 4-11.

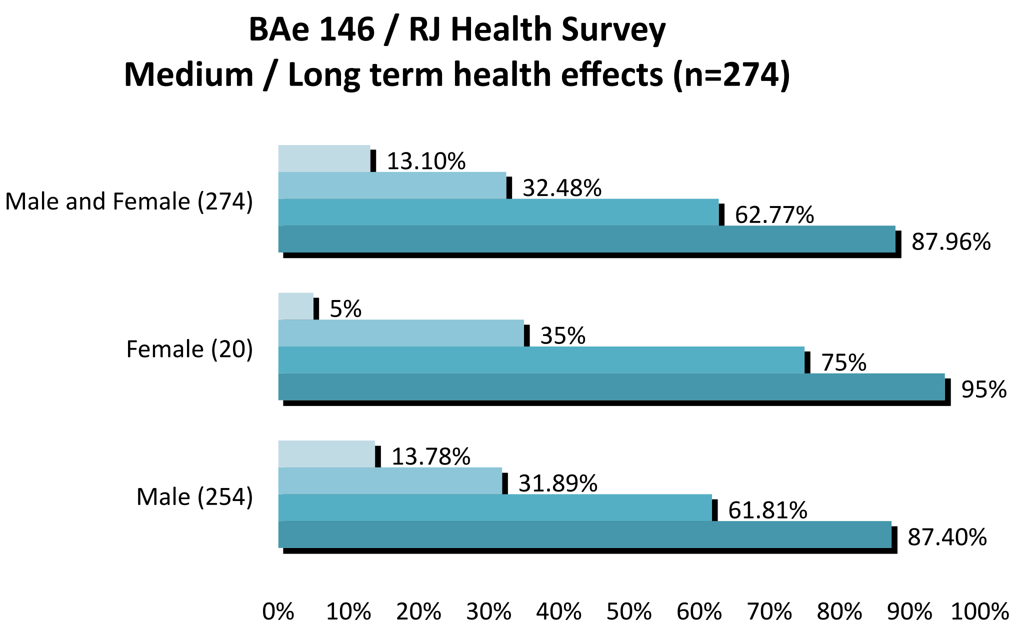
Examples of comments made by respondents about their medium or long term health problems included:

- *‘After 18 months on the 146 began to experience frequent ill health. Smelt "unwashed socks smell" particularly 1st flight of the morning. Symptoms increased in frequency and intensity and prevented him carrying out his duties competently as an FO. Was absent from work so often that he lost his medical on medical grounds’;*
- *‘Often smelt Dirty sock smell. Some aircraft worse than others. 1 ASR with fumes... Tech log entries made. Was off flying for a year and felt less tired and a lot better as a result. Has a rough throat, aches and pains but was unable to relate them specifically to the 146. Lethargic, skin rashes, short term memory, tingling in feet early morning, joint pain (taking tablets) extra heart beat here and there, sinus problems, chest infections...’*

Loss of ability to fly permanently

Significantly, 13% of pilots who were contacted or for whom data were obtained on their behalf appear to have lost their medical certificates to fly, lost their health in the long-term and ceased flying, reported ill health soon after retiring or were deceased, considered possibly relevant to contaminated air exposures. A close review of this group will follow.

Figure 4-11: BAe 146/146 RJ Reported medium or long term health effects



	Male (254)	Female (20)	Male and Female (274)
% of those contacted who had ceased flying with long term health effects	13.78%	5%	13.10%
% of those contacted reporting their health effects as medium or long term health effects	31.89%	35%	32.48%
% of those contacted who reported health effects	61.81%	75%	62.77%
% of those contacted who believed they had been exposed	87.40%	95%	87.96%

Symptoms data

Data on symptoms is broken down into groups of symptoms or organ systems. The data are then broken down into duration of the effect and time to onset. The original data for the specified health effects are available in Table 4-7 and should be reviewed to obtain an overview of symptoms being reported.

Table 4-7: BAe 146/146 RJ 2009 Pilot survey respondent breakdown

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Table 4.7: BAe 146 / 146 RJ 2009 survey respondent breakdown data by percentage (2009)

(n= 142)

Cluster	Symptom	Symptom	Immediate (same day)	Short term (days - weeks)	Medium term (wks - mnts)	Long term (More than 6 months)	Comment
General		Exhaustion	11.27	14.08	7.04	8.45	
		Joint Pain	0.7	2.11	0.07	6.34	
		Muscle pain	0.7	0.7		3.52	
		Muscle weakness		1.41	2.11	4.23	
		Chronic fatigue		1.41	2.11	13.38	
		Chemical sensitivity		2.11	0.7	8.45	
Nervous system	**Neuropyschological** (Mainly subjective or self reported – some symptoms may be better described in the neurological section below)	Headache	16.20	16.9	3.52	11.27	
		Dizziness	9.15	5.63	0.7	5.63	
		Disorientation	4.93	2.11		1.41	
		Intoxication	1.41	2.82		0.7	
		Confusion	70.75	5.63	3.52	7.04	
		Anxiety		0.7	2.82	5.63	
		Depression				5.63	
		Performance decrement	14.79	8.45	7.75	11.27	
		Memory loss	0.7		1.41	3.52	
		Memory impairment	9.86	8.45	7.75	17.61	
		Altered coordination	1.41	2.11	2.11	4.23	
	Neurological (Some self reported, but with clinical correlates such as medical diagnosis, MRI or	Vision problems	4.23	2.82	2.82	4.23	
		Nystagmus		0.7			
		Tremors	0.7	1.41		3.52	
		Shaking	2.11	0.7		2.82	
		Parasthesias (tingling)	3.52	3.52	3.52	7.75	

Cluster	Symptom	Symptom	Immediate (same day)	Short term (days - weeks)	Medium term (wks - mnts)	Long term (More than 6 months)	Comment
	clinical chemistry or cholinesterase levels)	Impaired nerve conduction		0.7		3.52	
		Vertigo	0.7	2.82	0.7	0.7	
		Balance problems	0.7	3.52	1.41	3.52	
		“Grey” outs	2.82	2.82			
		Seizures				0.7	
		Loss of consciousness	0.7				
	Senses - other	Hot flashes (body temp)	0.7	1.41	0.7	3.52	
		Taste	2.82				
Local effects	**Irritation**	Skin		1.41	0.7	3.52	
		Eyes	7.04	2.11		1.41	
		Upper airways	13.38	5.63	5.63	4.23	
	Skin	Itch		0.7		2.82	
		Rashes	0.7	0.7	1.41	2.11	
		Blisters (on exposed skin)	0.7	1.41			
	Respiratory	Breathing problems	3.52	2.11	3.52	9.86	
		Chest tightness/wheezing	0.7	1.41	1.41	2.82	
		Repeated chest infections					5.63
		Severe pulmonary problems					2.11
		Repetitive cough	0.7	2.11	0.7	3.52	
Systemic toxicity	**Cardiovascular**	Chest pain			0.7	0.7	
		Altered heart rate	0.7	0.7	0.7	7.75	
		Palpitations		2.82	1.41	3.52	
	Gastrointestinal	Salivation				0.7	
		Nausea	9.15	5.63	3.52	1.41	
		Abdominal spasms			0.7	0.7	

Cluster	Symptom	Symptom	Immediate (same day)	Short term (days - weeks)	Medium term (wks - mnts)	Long term (More than 6 months)	Comment
		Vomiting	0.7	0.7	0.7	0.7	
		Diarrhoea	0.7	0.7	2.11	1.41	
	Renal	Polyuria (frequent urination)				1.41	
	Endocrine	Hypothyroidy					
	Immunological	Increased incidence of cold/flu	5.63	2.11	1.41	2.82	
		Glandular fever					
		Altered thyroid function				0.7	
		Altered immune function			0.7	1.41	
		Allergies				1.41	
Cancer	**Cancer**						6.34

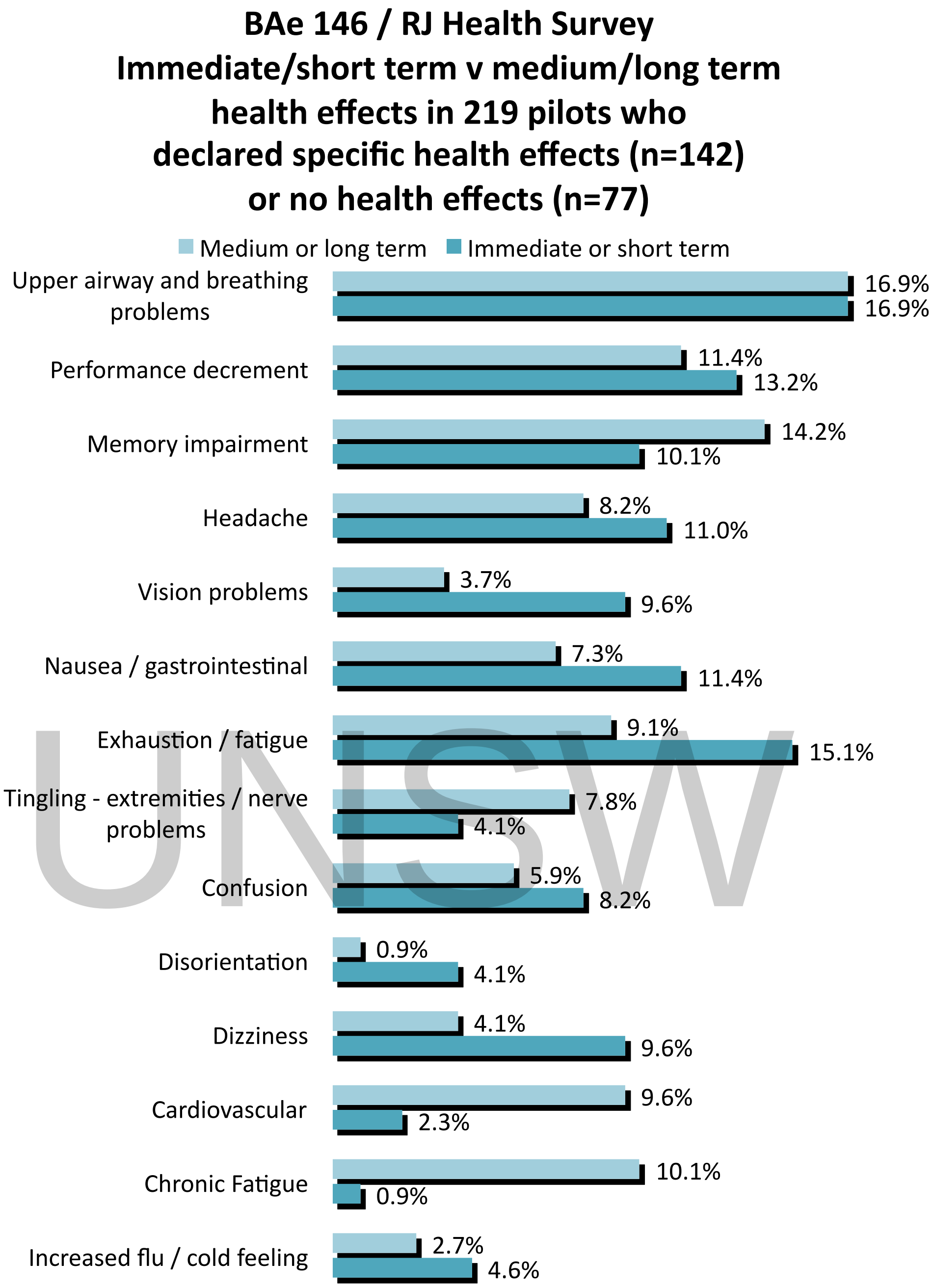
The data in Table 4-7 and Figure 4-13, Figure 4-14 and Figure 4-15 refer to selected symptoms only and cannot be classified into groups due to the overlap in respondent reporting. These data refer to the 142 pilots who advised specific effects. The data from the 219 pilots (Figure 4-12) will be looked at first followed by the data from the 142 pilots group (Table 4-7, Figure 4-13, Figure 4-14 and Figure 4-15). Figure 4-12 represents the data for the 219 pilots that include the 142 (52% of those contacted) who reported specific health effects and the 77 (28%) who advised they had not experienced any health effects. The numbers will be underestimated as 11% of those contacted advised they had experienced adverse effects but did not specify what they were or the duration of the effects, while 9% did not discuss health effects. The onset/duration is classified as immediate and short term or medium and long-term. The data were broken down so that there was no overlap in time period and selected symptom clusters sorted into groups. This data are of particular importance as there is no overlap and it is based on those who identified specific health effects as well as no effects.

Importantly, the data identify that over half (52%) the pilots contacted (n=274) reported some sort of adverse effect(s) while two thirds (65%) of the pilots who reported specific symptoms or no specific symptoms (n=219) reported that they had experienced adverse effects ranging from immediate to long-term.

It would be expected that the majority of those experiencing health effects that they did not declare would be immediate or short term or in some cases could be long-term if the individual thought these could not be connected to a chemical exposure. Given that it is expected that there is a strong element of under-reporting adverse effects, it is even more important to look carefully at the data of those who were prepared to report effects. This breakdown is shown in in Table 4-7, Figure 4-13, Figure 4-14 and Figure 4-15.

The data refer to selected symptoms only and cannot be classified into groups due to the overlap in respondent reporting. These data refer to the 142 pilots who advised specific effects. The data from the 219 pilots (Figure 4-12) will be looked at first followed by the data from the 142 pilots group (Table 4-7, Figure 4-13, Figure 4-14 and Figure 4-15).

Figure 4-12: Symptom clusters in 219 BAe 146/146 RJ pilots



It must be remembered that pilots are flying in a specialised environment and cannot be considered normal members of the workforce as there is no escape in flight and impairment in flight or of a continuing nature must be carefully reviewed at any level, particularly where there is an ongoing pattern.

While much of the data is self reported, the author is aware that the majority of medium and long-term (and even some short-term) effects were supported by documentation and diagnosis from the respondent's physicians. Additionally, as pilot's are required to hold medical certification by the CAA, the regulator will have been in most cases aware of the medium and long-term symptoms reported the by the pilot, whether the cause and full history of symptoms were identified to them or not.

Irritancy symptoms in eyes, skin, and respiratory and cardiovascular system

Data on irritation to the upper airway, skin and eyes as well as respiratory, cardiovascular and vision symptoms are presented in Figure 4-12, Figure 4-13 and Table 4-7.

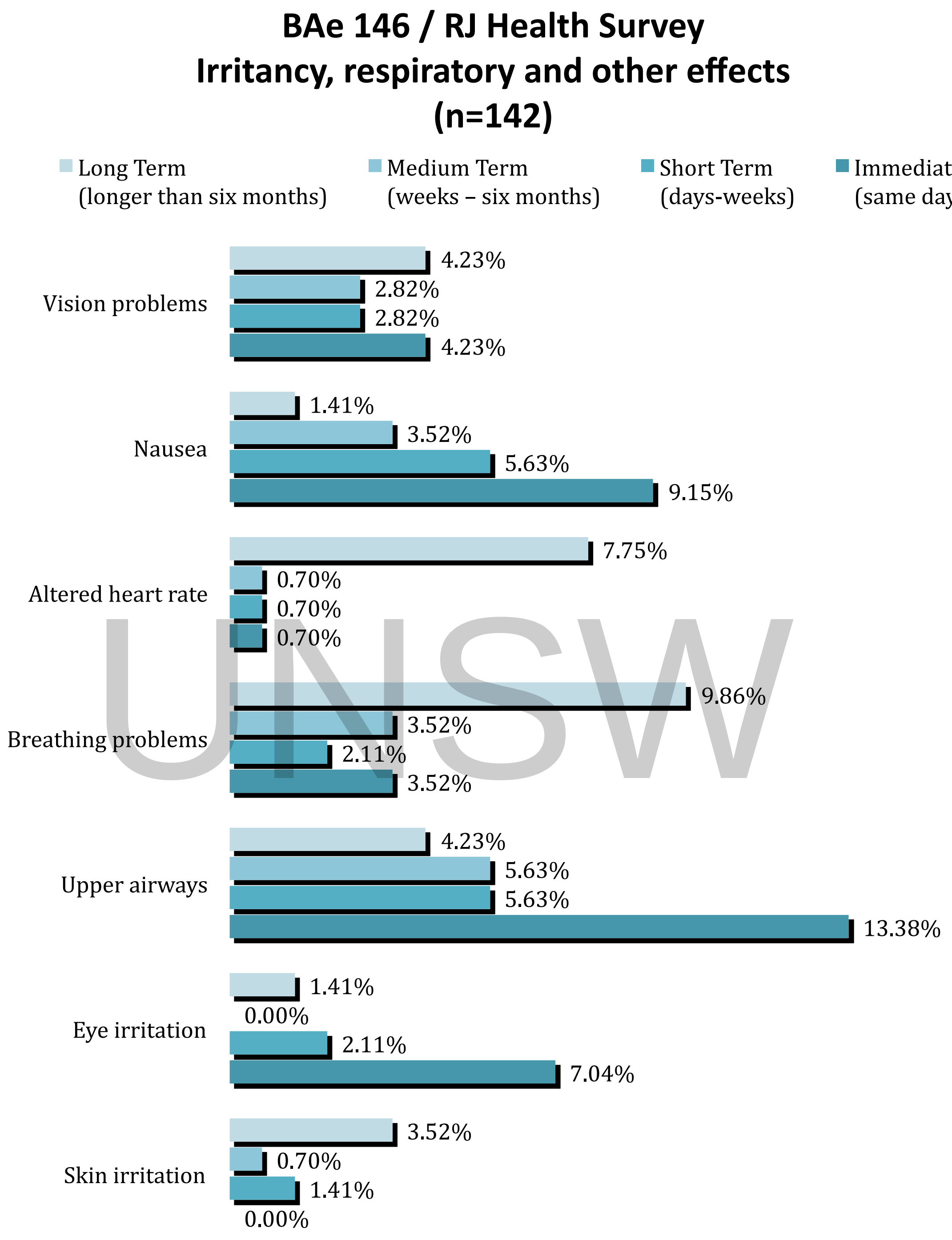
Given the importance of pilots flying aircraft, there are moderate levels of irritancy symptoms reported in these data consistent with exposure to irritant or hazardous substances. Vision problems are more of a short term and immediate problem (10%) consistent with the 11% of those (142) pilots reporting specific symptoms of eye irritation and vision problems immediately, continuing to a lesser extent (~5%) in the short term through long-term.

While skin irritation as an ongoing problem is reported at 4%, 8% are reporting skin irritation, itch or rashes on an ongoing long-term nature.

Direct respiratory symptoms consistent with exposure to respiratory irritants or hazardous substances are also reported. Upper airway and breathing problems (chest tightness, wheezing, breathing problems and repetitive cough) are reported on an equal basis for immediate and short term (17%) and medium to long-term (17%). This is supported by the 142 pilots reporting upper airway problems immediately at 13%, ongoing through the short-term, medium and long term at 6%, 6% and 4% respectively. Breathing problems, on the other hand, in those reporting specific events show a reversal with more pilots reporting long-term breathing problems at 10% and around 3% in each of the other categories.

The 142 pilots reporting specific events also reported a 6% rate of repeated and ongoing chest infections, while 2% reported severe pulmonary problems in addition to the above rates.

Figure 4-13: Selected local, respiratory and other health effects in 142 BAe 146/146 RJ pilots



Cardiovascular effects, manifested as altered heart rate, palpitations and chest pain are evidently more of a medium to long-term problem for the pilots (10%), while at the lower 2.3% rate in the immediate and short-term. The 142 pilots reporting specific events reported altered heart rate as a long-term problem at 8% and much lower rates in the other categories. Chest pain and palpitations also support the trend for longer-term effects at 4%.

Nausea and gastrointestinal symptoms are shown as more of an immediate/short-term problem at 11% with 7% reporting medium to longer-term effects. This is supported by the specific effects data showing 9% reporting nausea immediately, 5 % in the short-term reducing over time.

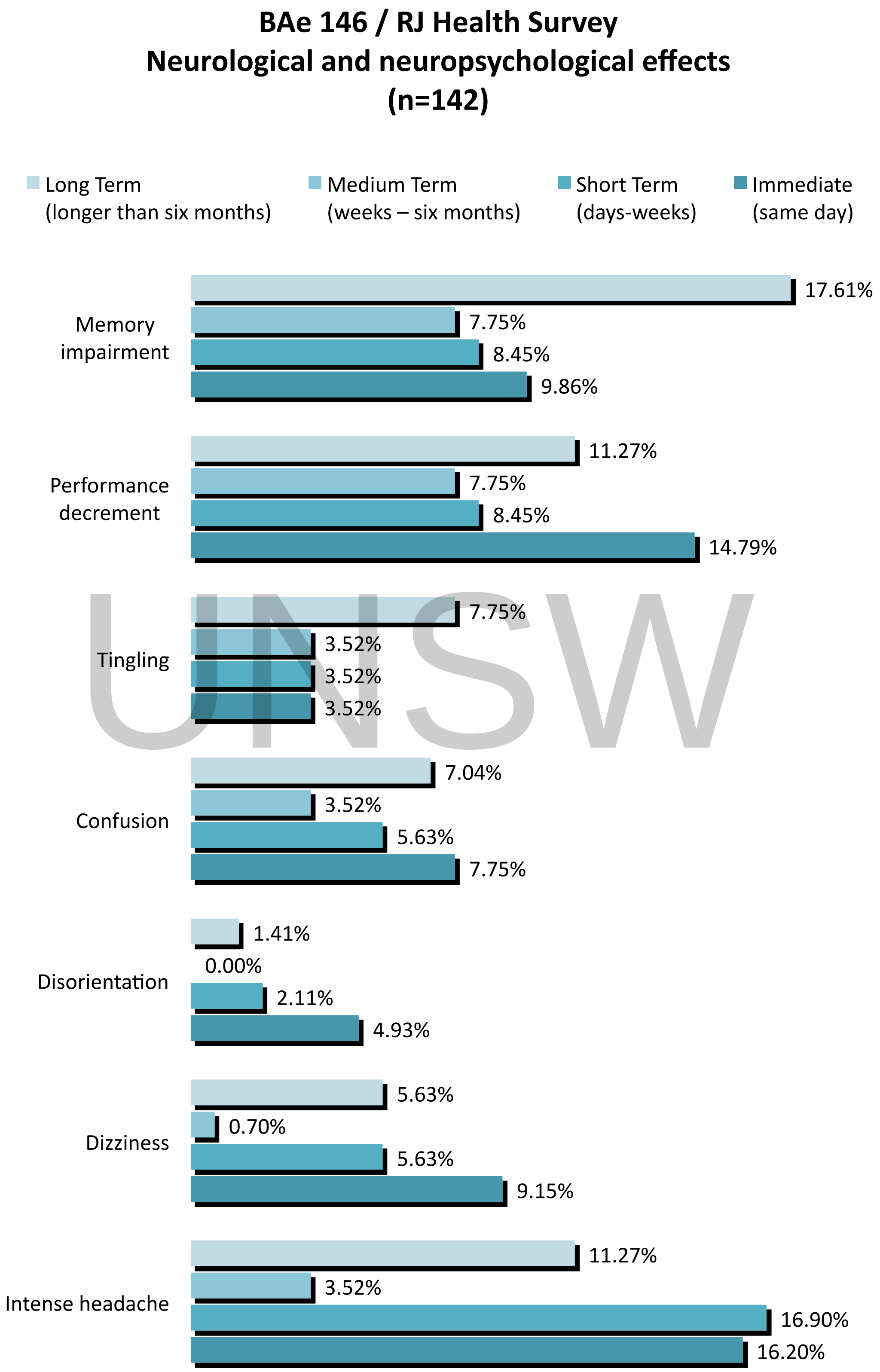
Upper airway and breathing problems, eye irritation as well as nausea were reported as the principal immediate and short term effects, while continuing breathing problems and cardiovascular symptoms were the major symptoms reported in the long-term.

Adverse irritant and respiratory health effects are well recognised as a result of exposure to, among others, oxides of nitrogen, ozone, sulphur dioxide and particulates, either singularly or in combination, such as in exposure to aviation products which have been known for some time. [8,9,13,18,19,21,27,71] An association between high occupational exposure to aviation fuel or jet exhausts and upper and lower respiratory tract symptoms is in keeping with exposure to a respiratory irritant. [72] Occupational asthma is recognized to occur in certain industries with causative agents including chemicals, [73] while airway hyperactivity can be caused by selected organophosphates. [74] Oil and lungs are recognised as being incompatible as there is a great potential for airborne substances to cause injury to the respiratory tract with inhaled substances varying in their ability to cause irritation through to lung disease. [75,76] Direct aviation industry awareness regarding respiratory irritation and or lung injury extends back many years. [26,39,77,78,79,80,81,82,83]

Neuropsychological and neurological symptoms

Data on neuropsychological and neurological symptoms reported in pilots surveyed are shown in Figure 4-12, Figure 4-14 and Table 4-7.

Figure 4-14: Neuropsychological and neurological health effects in 142 BAe 146/146 RJ pilots



Once again, these data must be looked at in context of the occupational setting and specific role undertaken by aircrew. The neuropsychological reporting of headache, dizziness, disorientation, confusion, memory impairment and performance decrement are critical for pilot performance. The Norwegian CAA aeromedical office stated *'even small neuropsychological defects can affect the pilot's ability to perform his/her duties safely in an ever increasingly complex aviation environment.'* [42] Cognitive deficits in pilots during a critical phase of flight might be devastating according to a USAF study. [61]

Symptom reporting rates are highest for those reporting immediate and short-term performance decrement (13%), followed by headaches (11%), memory impairment (10%), dizziness (10%), confusion (8%) and disorientation (4%). In the medium and long-term the one symptom that rose was memory impairment (14%) with a number showing slight increases but importantly the ongoing nature of the symptoms should be noted: performance decrement (11%), headaches (8%), confusion (6%) and dizziness (4%).

The 142 pilots reporting specific effects supported the above trends with headaches reported at high levels in the immediate and short term (16-17% each) but with a continuing trend at 11% in the long-term.

Memory impairment was reported at 10% and 8% in the immediate and short-term while there was a considerable rise to 18% in the long-term. Performance decrement was recorded at 15% and 8% in the immediate and short-term and decreased to 11% in the long-term but was indicative of an ongoing problem.

Dizziness and confusion showed a small decrease over the long-term but were certainly an ongoing significant problem. Intoxication was reported at lower levels more so in the immediate and short-term, with anxiety and depression recorded at lower levels as more of a longer-term issue. Altered co-ordination was a slightly more medium and long-term problem reported by 2% and 4% respectively.

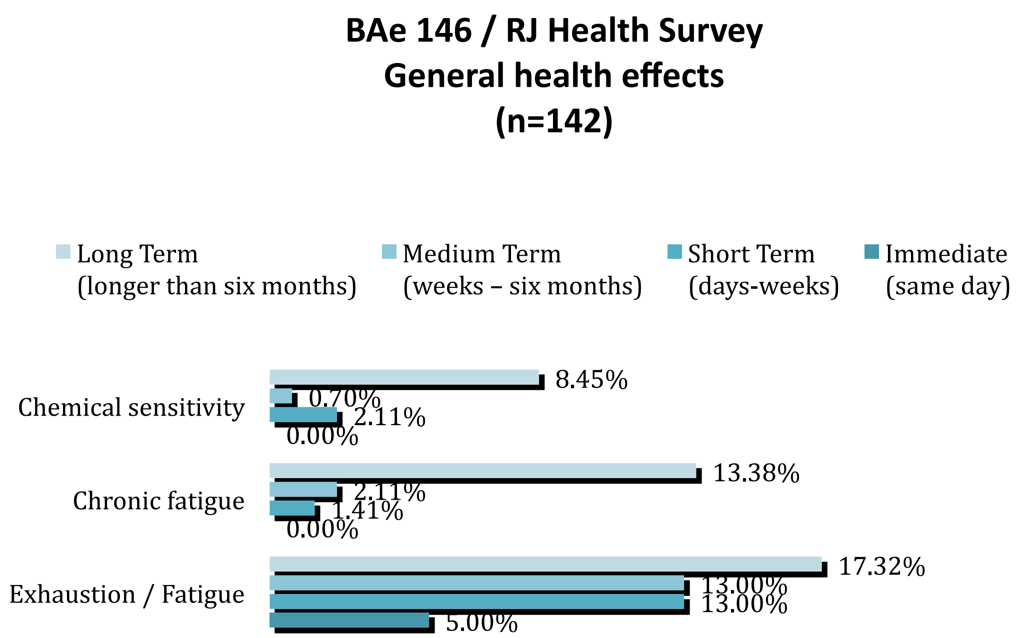
The neurological symptoms show more of a long-term issue with 8% reporting tingling in the extremities and nerve problems/numbness in the medium to long-term and 4% in the immediate to short-term. Of the 142 pilots reporting specific effects 8% confirmed parasthesias (tingling) in the long-term with around 4% of crew reporting the condition both immediately and shortly after flight. Balance problems were reported in both the short and long-term at around 4%. Tremors and shaking were reported at low levels in the short and longer term, while numbness or impaired nerve conduction was reported as more of a long-term problem at around 4%.

Vertigo was reported at low levels in the short-term along with grey-outs (loss of behavioural function but not consciousness), loss of consciousness and nystagmus.

The neurological and neuropsychological symptoms reported here are quite specific to a strong exposure history and are consistent with exposure to volatile organic compounds, [30] organophosphate compounds [31] and/or carbon monoxide. [32] These exposures should not be dismissed in such a critical occupational setting where underreporting of symptoms is suspected and confirmed, due to the conflict with fitness to fly, aviation regulations and job security.

General signs and symptoms

Figure 4-15: General signs and symptoms in 142 BAe 146/146 RJ pilots



Exhaustion and fatigue were reported as the main immediate and short-term symptom in the 219 pilots at 15%, with the medium and long-term rates reported to continue on at 9%. Chronic fatigue was reported at 10% in the longer-term. In addition to symptoms and signs in specific organ systems, a range of multi organ or general symptoms was reported as shown in Figure 4-12, Figure 4-15 and Table 4-7.

Of the 142 pilots reporting specific effects, exhaustion and fatigue were reported increasing over time at rates of 5 % immediately, increasing to 13% in the short as well as the medium term and peaking at 17% in the long-term. Chronic fatigue was identified in 13% of long-term cases. Chemical sensitivity was reported in the long-term by 8% of the 142 pilots. Joint, muscle pain and muscle weakness was reported as more of a long-term at around 5% in each group.

A range of other symptoms and diagnosis were reported and generally not included in the above figures. These included but were not limited to: Stage 4 GBM brain tumour in two BAe 146 pilots flying for the same company after long-term exposure and shortly after cessation of flying; tongue cancer (1) in a young male non smoker, lung cancer in a 40 year old male non smoker who reported concerns about chemical exposures in the workplace; Lymphoma (1); Colon cancer (1); Bowel cancer (1); Motor Neurone Disease (1) and unexplained severe intermittent liver problems (3), thyroid (1) and tumour on spine (1).

Of all the general symptoms, fatigue and exhaustion leading to chronic fatigue were the most widely reported and are of course a direct threat to aviation safety. [84]

Long-term ill health

Thirteen percent (36 of 274 contacted) of pilots report that they have suffered ill health and lost their medical, retired with ill health or suffered ill health soon after retirement or were deceased with a history of exposures and considered possibly relevant to this survey. Only 1 of the 36 was female. The main reasons for ill health have been summarised in Table 4-8 showing the breakdown of the long-term ill health pilots. In most cases, the data do not provide diagnosis, however, all non-retired pilots will have had to provide their doctors and the UK CAA with data on their ill health with subsequent diagnosis from their consultants. In many cases the author has sighted the reports.

Table 4-8: Long-term ill health/medically retired/deceased pilots

#	Age below 45	Years on BAe 146/RJ	Exposure	Symptoms identified for long term ill health
1	✓	3-5	E,B,V,F	Cardiac, respiratory, general, neuropsychological, neurological
2		11+	E,F	Neuropsychological
3		6-10	E,F	Neuropsychological, neurological, respiratory, general
4	✓	6-10	E,B,F	General, neurological, neuropsychological
5		11+	E,B,V,F	Neurological, respiratory
6		11+	E,B,F	Neuropsychological general
7		11+	E	Alzheimer's – frontal Lobe degeneration. Onset 60
8		11+	E, V, F	Brain tumour: GBM 4 (60+)
9		11+	E, V, F	Neurological, neuropsychological, general
10			E	Cardiovascular
11		11+	E,F	Respiratory, general
12	✓		E,B	Neuropsychological, general
13				Neuropsychological
14	✓	3-5	E,B,F	Neuropsychological, neurological, respiratory, cardiovascular, general
15		11+	E,F	Motor Neurone Disease. Onset 63
16		6-10	E,B,F	Possible mild Parkinson's, General, neuropsychological. Onset under 55
17		1-2	E,F	Neuropsychological, respiratory
18		11+	E	Cardiovascular, general
19		11+	E,B,V,F	Neuropsychological, neurological, general
20		3-5	E,F	Cardiovascular

#	Age below 45	Years on BAe 146/RJ	Exposure	Symptoms identified for long term ill health
21		11+	E,F	Neuropsychological, neurological, general, respiratory
22		11+	E	Thyroid, liver
23		3-5	E	Alzheimer's /changed to chemical induced neurological injury, Corticobasal degeneration – Onset 61
24		11+	E, F	Neurological, neuropsychological, respiratory (MSSA)
25		6-10	E, F	Neurological, respiratory, cardiovascular
26		11+	E	Neuropsychological, neurological, general, respiratory (MSSA)
27	✓	1-2	E,B,F	Neuropsychological, neurological, respiratory
28	✓	6-10	E,F	General, respiratory
29			E	Neuropsychological
30		3-5	E,F	Neuropsychological, GI
31		11+	E,F	Brain tumour: GBM 4 (60+)
32	✓	6-10	E,F	Neuropsychological, neurological, general, respiratory, cardiovascular, GI
33	✓	6-10	E	Neurological
34				Colon cancer
35	✓			Lung cancer (NS), 41
36		6-10	EV	Neuropsychological, neurological, general , respiratory
E = exposed; B = 1 or 2 more identifiable events; V = visible mist/smoke F= repeatedly or frequently exposed				

A number of significant findings can be drawn from this table along with the additional data sighted by the author. These include:

- A significant number (13%) of pilots have been ill health retired or lost their health after flying on the BAe 146/RJ;
- History of frequent exposure to fume events was a greater issue than one or two bigger events or visible mist. 36% for those experiencing the ongoing long-term ill health (retirement…) reported frequent exposure, while frequent exposure along with a bigger event or mist was reported in more cases than a one off event or mist exposure, thus indicating frequency of exposure is playing a significant role;
- The symptoms/diagnosis reported fit the general pattern of neuropsychological, neurological, respiratory, general and cardiovascular seen in the previous data;
- The highest reported symptoms/diagnosis involve neuropsychological (64%), followed by neurological (53%); general (fatigue, GI, chemical sensitivity, weakness...) (53%); respiratory (39%) and cardiovascular (25%) with under-reporting also well-identified;
- Brain tumours - Stage 4 GBM in 1% (2 cases) of pilots reporting specified symptoms or no symptoms or 6% of the long term ill health pilots;
- Alzheimer's reported in two cases (1% of pilots reporting specified symptoms or no symptoms or 6% of the long term ill health pilots) with one revised (misdiagnosis) to be chemical induced neurological injury (Corticobasal degeneration) showing almost the same pattern as the breakdown categories;
- The pilot diagnosed with motor neurone disease (MND) was medically retired four years before being diagnosed with MND for an ectopic heartbeat. He was well aware of exposures but considered it normal and advised he was certain the contaminated air exposures led to his MND; [85]
- 2 pilots were diagnosed with sarcoidosis (6% of the long term ill health pilots) leading to temporary loss of medical and initially not considered as relevant to cabin air contamination. After return to work, both pilots subsequently retired on ill health grounds with wide range of symptoms falling into pattern considered consistent with contaminated air

exposures. In one of the cases, this data was not included fully in the respiratory effects as this was unknown to the author at the time;

- Other diagnoses given were ectopic heartbeat; suspected toxic neuropathy and encephalopathy; Aerotoxic Syndrome; organophosphate poisoning; Aerotoxic Syndrome/CFS/MCS/neurological damage; possible mild Parkinson's, Cardiac Arythmia; inhalation of hydrocarbon fumes; sarcoidosis...;
- Long-term ill health retirement occurred most frequently in those having flown the aircraft for 11 or more years (16 or 44%) then 6-10 years (8 or 22%); 3-5 years (5 or 14%) and 1-2 years (2 or 6%);
- Those over 45 were more likely to retire on ill health grounds, retire with long term ill health or be deceased (considered possibly relevant) at (27) 75% with those under 45 (9) listed at 25%. For those under 45, the greatest likelihood of ill health retirement/long-term ill health (deceased) was for those who flew the aircraft 6-10 years (4 or 11%); followed by 3-5 years (2 or 6%); 1-2 years (1 or 3%);
- 5 of the 36 long-term/retired ill health pilots had previously taken extended time off work, whereas an additional 12 pilots who did not medically retire or go on to experience further ill health (as far as the author knows) took extended time off work subsequent to adverse effects, regular exposure events and major incident events.

Additionally, 5 of the 36 pilots in the retired ill health group did not complete their career on the BAe 146/RJ but all others did. This group of five identified the onset of adverse health whilst flying on the BAe 146/RJ and in two cases (both under 45) took extended time off work. Two of the pilots went on to fly the Fokker F70/F100 (after the BAe 146/RJ) for some years when their health subsequently caused them to medically retire. Another commenced flying on the B757 and experienced an immediate escalation of adverse symptoms leading to cessation of flying. One of the pilots took extended time off work (several years), then flew unpressurised aircraft for a period and within a short time of regaining employment on a small bleed air *'pressurised'* aircraft, after a noticeable fume event, was forced to medically retire due to a further escalation of the previously existing symptoms. The fifth pilot, after more than 11 years on the BAe 146, flew for several years on a Boeing 757 but suffered an escalation of *‘general’* symptoms, which caused him to medically retire. It is interesting to note that there is an over representation of pilots under 45 in this category (3) with an over representation of having operated on the aircraft for less years (3-5 × 2; 1-2 × 1; 6-10 × 1). This pattern suggests that the adverse effects experienced on the BAe 146/RJ played a direct effect in later health problems with some individuals experiencing escalation of adverse effects very soon after flight on an alternate aircraft type, while both Fokker pilots flew for some years before an escalation of adverse effects.

The majority of those having had to cease flying or experiencing long-term ill health, as shown in Table 4-9 fit into the categories of neuropsychological, neurological, respiratory, general and cardiovascular, reported a fairly constant range of symptoms, apart from slight improvement over time (still remaining severe) and avoidance of aggravating factors. There seemed to be the most improvement in those only identifying cardiovascular symptoms on their own. Those reported with cancers or severe neurological conditions showed a decline in health as expected.

Table 4-9: Breakdown of long term ill health/medically retired/deceased pilots

Symptoms/diagnosis	Number (n =36)	Per cent
Neuropsychological	23	64%
Neurological	19	53%
General	19	53%
Respiratory	14	39%
Cardiovascular	9	25%
Brain tumour GBM4 × 2; colon cancer × 1; lung cancer × 1; Alzheimer’s × 1 (frontal lobe degeneration); Corticobasal degeneration x 1; possible mild Parkinson’s × 1; MND × 1		

Of the twelve pilots taking extended time off work, the adverse effects identified included:

- *'After major exposure event and extended time off work, major ruptured brain aneurism occurred after renovation of house and sensitivity to chemicals identified;*
- *Doctors asked if pilot diagnosed with Gillian Barre Syndrome had ever worked with organophosphates (pilot was not aware he had); taken ill on aircraft (asthma?) and found to have reduced breathing capacity to 40% and took one year off to recover;*
- *Time taken off work with typical symptoms then child died soon after birth with Congenital diaphragmatic hernia (CDH). Both parents flew on BAe 146 and advised of links with certain pesticide exposures.'*

Since completing the survey, the author has been approached directly by additional pilots suffering ill health who were uncontactable during the survey. In one case, the pilot advised after 17 years flying on the BAe 146, he had recently been diagnosed with Goodpasture's syndrome (an autoimmune disease associated with hydrocarbons [86]) with his doctor asking if he had ever been exposed to oils, while another had recently undergone surgery for nasal polyps and another cancer was reported. Another pilot, also not included in the survey data, reported medical retirement 4 years after commencing flight on the BAe 146 (previous long military & commercial airline career). The pilot reported the standard pattern of ill health being reported (general, neuropsychological, neurological, gastrointestinal, cardiovascular), particularly noting respiratory symptoms, and a series of repeated chest infections for which his pilots' medical was suspended, followed soon after by an MI. The pilot reported contaminated air was viewed as regular and normal and advised that he experienced the same pattern of symptoms ongoing 16 years after cessation of flying.

There was a range of diagnoses given for this group of long-term ill health pilots with some being misdiagnosed. The misdiagnoses included:

- Bi polar disorder (medicated till lost mental capacity) then corrected to 'chemical induced nervous system injury - suggesting moderate brain injury', PTSD and Aerotoxic Syndrome - under UK Brain Injury Rehabilitation Trust;

- Possible mild Parkinson's;
- Clinical depression (CAA) then Alzheimer's changed to chemical induced; neurological injury with corticobasal degeneration;
- MSSA (2 cases) due to vocal polyp operation and infected sinus operations that went wrong, however doctors now support Aerotoxic Syndrome, toxic chronic encephalopathy and autonomic neuropathy respectively;
- Chronic stress changed to Aerotoxic Syndrome/Chronic poisoning;
- Clinical depression changed to peripheral neuropathy and chronic exposure to toxins;
- Clinical depression (CAA), then epilepsy then Alzheimer's, now said to be chemical induced neurological injury;
- Likely not simple partial epilepsy.

Discussion

Identified issues

The survey clearly highlighted a number of interesting trends that not only substantiate the reluctance of pilots to talk about the contaminated air issue, but also operational practices that are noteworthy. [59]

- Lack of awareness of effect (symptom range and severity) of contaminated air exposures, which were seen as ongoing and normal, therefore leading to under-reporting. Many pilots acknowledged this and some suggested greater vigilance in the future as they now had a very different view;
- Numerous pilots reported the exposures and symptoms but did not always link the two;
- There was a major lack of awareness of chemical exposure effects shown by doctors;
- Apart from the initial written questionnaire, the reporting was far more effective with a symptom list supplied to respondents rather than the initial telephone call method and more effective again with the more

detailed form which detailed symptom onset and duration. However there was a variation in interpretation in some cases;

- There was a strong reluctance to talk openly about the symptoms and exposure history, with numerous pilots reporting brief personal history until requestioned or requested to provide further information, then providing a more thorough history. In a documented case, one pilot advised no adverse effects after 11+ years operating the aircraft, yet 3-4 years later advised long-term/intermittent general, neurological, neuropsychological and respiratory effects that had been going on many years. Others advised greater health effects than reported but failed to provide an updated list as agreed.
- Despite 2% of the population being recognised as having no sense of smell, [69] and given the strong documented awareness of the fume exposure issue (from airlines, manufactures and regulators), which pilots ought to have been aware of, 12% of respondents claimed they had not been exposed with 9% saying they were not aware of the issue. In a number of cases, pilots would claim they were not aware of the issue and 'none' of their colleagues had ever smelt the fumes or had adverse effects;
- Some pilots, who were known to have been involved in documented major incidents, denied any adverse effects, despite the official incident report recording serious adverse effects during and after the event or to both pilots. In some cases a pilot would deny any adverse effects or exposure, yet a colleague would advise they had been in a particular event with the other pilot and the other or both pilots had experienced adverse effects;
- Some pilots, who were not contactable were said to have been involved in a major incident (by the other pilot in that event) with severe adverse effects requiring hospitalisation and extended time off work, yet are listed under *'health effects unknown',* thus reducing the reporting rate in some of the data;

- Airline management pilots were far less likely to respond. Of those contacted all but one stated they were aware of the fume events but had not experienced any adverse effects or were unaware of any others affected adversely. This was interesting as many were known to have debriefed crews who had officially reported adverse effects during reported contaminated air events;
- There was a very clear pattern of the majority of past and present aircraft manufacturer company pilots being unwilling to participate in the survey, despite repeatedly acknowledged strong patterns of ill health from colleagues. A number of these pilots were listed as working for the CAA and other industry bodies;
- Pilots advised they turned the temperature up very high to burn off the fumes, and advised passengers this was normal, while others advised passengers the fumes were toilet fumes so as to not worry them;
- Adverse effects would often clear when away from work (short or long term) and return upon workplace further exposure;
- Unable to follow up numerous crew who advised immediate/short-term or medium to long-term effects as further contact was not possible;
- Some pilots reporting non declared adverse symptoms raised concerns of long-term exposure on the aircraft and the effect on health and the implication for the job;
- There was a noted level of aggression by some at raising this issue along with denial of exposures and adverse symptoms such as *'unjustified scare causing widespread panic for no reason'* or *'not a good idea to "rake up" this issue as it is bad for the industry';*

Many comments of interest were made, of which a few are listed below:

- 'Chest pain through 80 knots';
- Most retired (manufacturer's) pilots have ill health with *'most having either Alzheimer's or cancer';*
- *'During time on the 146 often suffered from headaches, and used to "eat paracetamo"';*

- *'Fumes were a standing joke. Always smelt oil and considered this normal';*
- Manufacturer advised by an airline at a meeting that *'one of their pilots had chemical burns in throat' and asked what was going to happen'* Manufacturer cancelled meeting immediately;
- *'Flight Safety Officers have requested that less reporting is done on cabin air incidents as the paper work is building up and costing money to process';*
- *'After about a year on the BAe146, I started to have concentration difficulties in airspace with high workloads... I started to experience dry eyes and throat, ...more intense effects were feelings of euphoria, intoxication, lack of concentration, with difficulty in doing simple fuel calculations, then later tingling in forearms, calf and thigh muscles...';*
- *'xx (airline) Doctor NEVER rang';*
- *The incident was not entered into the tech log, However it was passed over the phone to engineer;*
- *'Every time you flew you could smell socky smell especially on G--- AS "ALPHA STINK"… Everyone complained about the smell and "aircraft stinks of socks" written in the tech log quite regularly then crews got used to it and did not report any more';*
- *'Headaches, nausea, fatigue. After a few days off I feel so well that the aircraft must be the problem';*
- *'Complete loss of oil in engine No 2... 2 hours later mild headaches, skin rash (hives) on legs and arms spreading to back that night. Next morning sore throat with acute ulcerations in back of throat lasting (white spots) 2 weeks...';*
- *'Forced to go on Dash 8 as was getting mysterious illnesses and fatigue and airline said had to go on Dash 8...';*
- *'Returned to work feeling permanently washed out and fatigued, chest pain… considered fit to fly by CAA Doctor… Felt forced to fly to avoid financial penalties... Could not pass checks and opted to no longer fly';*

- *‘After repeatedly experiencing fumes and blue hazes and suffering a range of symptoms, clinical depression was diagnosed by the CAA psychiatrist and I was hospitalised and put on heavy medication which made me very ill… I was fighting for my life… severe shaking and tremors. Improved immediately after taken off drugs... 5 years later I was left with severe burning sensation and peripheral neuropathy was diagnosed. (25000 hrs total flight time, 11+ on BAe 146). I was 53 when I became ill, it has left me with memories of hell, it has cost me 7 years of my career, which I worked so hard for’;*
- *‘Presently off work with severe migraines (previous range of typical symptoms/exposures) and wonder if the 146 is making me ill and company is not being straight with me’;*
- *‘Frequent black acrid smoke filling the cabin on starting the APU and most 146’s had the all pervading rancid smell – but this we considered “normal” at the time’...* Although medically retired and left with long-term breathing difficulties, chemical sensitivity, muscle weakness and pain and memory impairment the pilot advises *‘I have no real long term problems’;*

Deterioration in condition over time identified: Earlier on in the survey period pilots would report ongoing adverse health effects with deterioration over time. One example being:

- *‘My experience is mainly of the packs smelling first thing in the morning when they are first switched on. After 5-10 minutes the air-con system seems to settle down and the cabin fumes mainly or totally disappear. It is something we have all become used to. Some aircraft are worse than others... I have never experienced a major in-flight emergency; I feel the cabin air quality is not to be trusted, despite assurances from various quarters. Many symptoms I have put down to a hard schedule, fatigue etc but I am now suspecting the contamination. My principle symptoms are a deteriorating short-term memory and more headaches than is normal for me. Major event in XXXX ...severe headache and nausea, repeat events: difficulty concentrating, foggy, time off to recover, difficulty doing household tasks… then lost pilot medical in XXXX left with headaches (intoxication feeling), occasional vertigo, grey-outs,* *exhaustion, chemical sensitivity, memory impairment, skin, respiratory problems...'*

Other issues

While the data cannot be said to be complete given the inherent and clearly identified problems in getting pilots to talk about an ongoing work related problem that could go against their airline's commercial interests and the individual pilot medical certification requirements, this survey still reveals very significant data in a group of randomly contacted commercial pilots. Additionally, the methodology in obtaining the data presents problems as unlike previous surveys, the pilots in most cases were not presented with a list of symptoms to aid selection, onset and duration. However, as time went by over the four years, a more thorough survey form was used, aiding data collation and confirming how a detailed questionnaire will generate more data than an individual's instant memory recall to self report.

Clearly the recognised problem [60,61,62,63,64] of getting pilots to report medical data was seen in this survey. The reluctance to divulge information was very evident and pilots in some cases denied knowledge of a problem that all ought to have known about or there were data indicating they were aware of the problem, pilots who had previously denied knowledge later divulged a history of adverse effects, while others apparently assumed certain symptoms or diagnosis were not relevant to the survey. However, given the critical importance of contaminated air exposures for crew and passenger health and flight safety, this data from a group of mainly working pilots should not be ignored.

Overall, the data provide the first in depth snapshot of adverse health effects being experienced by pilots who identified significant exposure history (88%) to *'predominantly'* oil fumes from the engine or APU as previously acknowledged by the aircraft manufacturer. [87] A small selection of the survey respondents were then clearly asked to provide further data about the exposures. 34% of the contacted pilots reported frequent or repeated exposure, while 19% identified one or two more identifiable events and only 7% reported visible mists. However, time since exposures and the survey process are likely to have reduced the break down categories of exposure information significantly.

The data presented here supported with other industry documentation for this aircraft type, show that fume event exposure and awareness of the contaminated air issue was extremely high, residual ongoing fume events were more of an identified issue than the one or two more identifiable or memorable events and visible fumes. Fume events were almost exclusively seen as the result of exposure to oil fumes/mists in the aircraft. They were seen as a long-term ongoing issue occurring both on the ground and in certain stages of flight. The fumes were in fact seen as so normal and routine with some pilots reported regularly turning the temperature up high in the morning to burn off the oil. This is similar to a pack burn procedure, which had the same effect and was routinely carried out by some airlines on a daily basis. However it was identified in 1997 and reported to operators that pack burns could result in high levels of hydrocarbons during this operation and for some time after and as such pack burns should not be carried out on a routine basis. [88] BAe advised pack burns should no longer be undertaken in 2000, while ASHRAE advised such procedures were not effective and should not be undertaken with crew or passengers on board. [89,90] While it was not possible to quantify the level of exposure during such events, the widely reported level of symptoms both during non-visible and visible fume events suggest significant exposures. The well known 1999 Swedish BAe 146 incident in which no visible fumes or obvious smell was reported, a number of oil leaks were positively identified (along with synergistic mix of chemicals) and the crew were totally incapacitated in flight, gives the best indication of the levels of exposure and their subsequent effects. [23,91,92]

It is important to recall that this was not a self selected group and involved in the main (238) working pilots or retired pilots with 36 (13%) either ill health retired or experiencing chronic ill health. Therefore it is expected this should be a healthy population, particularly as pilots are required to undertake regular medicals (annual or six monthly) to confirm their ongoing health and fitness to operate as a commercial airline pilot. It is also noted that documented under-reporting of adverse symptoms is evidenced with reasons already stated. Therefore, the reporting of adverse symptoms in this population is a key finding and will be different to data obtained from self selected candidates. The current survey details an overriding concern about job security and medical certification compared to health effects, whereas it has been shown to be more balanced or reversed in a group of self selected pilots leading to higher numbers. However, despite this obvious dilemma, the numbers are high for a working population employed in a critical safety position.

There were clearly three categories of exposure and ill health identified. Firstly there were those who reported no ill effects. The next group consisted of 44% reporting immediate or short-term effects and a group of 32% reporting medium or long-term symptoms. In total 63% of pilots reported experiencing adverse health effects. There was a smaller subset who reported long-term symptoms and various significant diagnoses and who also reported a long exposure history. This subset had not been particularly aware of adverse effects at the time of exposures (may have been some years back) but generally considered the fumes normal and frequent.

Based on the 219 pilots who advised specific effects or the alternate, there are a number of symptoms reported in the immediate and short-term, some of which are consistent with exposure to *'hazardous'* substances based on the Australian and EU and similar criteria. [93,94] The main immediate/short-term symptoms identified include upper airway irritation and breathing problems (17%) eye irritation and vision problems (10%) and cardiovascular issues (2%). Neuropsychological symptoms reported include performance decrement (13%), intense headaches (11%), memory impairment (10%), dizziness (10%), confusion (8%), disorientation (4%) and others such as intoxication and shaking. Neurological symptoms involved tingling in the extremities and nerve problems (4%), tremors, shaking, loss of balance, vertigo, grey-outs, loss of consciousness and nystagmus. General symptoms include fatigue and exhaustion (15%) and nausea (11%) with lower levels of joint and muscle pain/weakness.

This survey supports previously published data showing that not all symptoms receded after cessation of exposure with a number becoming more debilitating and lasting into the medium to long-term category. The upper airway and respiratory symptoms continued on at 17% with the majority related to breathing problems, chest tightness, repetitive cough, repeated chest infections and selected more severe pulmonary problems. There was a noticeable increase in cardiovascular symptoms (10%) such as palpitations, altered heart rate and chest pain. Skin irritation also identified as a rash or blisters became more noticeable at around 8%. Neuropsychological symptoms continued on with memory impairment increasing to 14%, performance decrement and intense headaches decreasing only slightly to 11% and 8% respectively. Dizziness and confusion remained in the long-term at only slightly lower levels, with altered co-ordination increasing slightly. Anxiety and depression only became apparent in the medium to long-term, which of course could be justified as a secondary result of the health problems and medical certification concerns. The neurological symptoms that became more pronounced over the long-term involved, tingling in the extremities and nerve problems, doubling to 8% with tremors and shaking becoming more noticeable around 4%. The general symptoms became more prominent with exhaustion and fatigue lowering only slightly to 9% with chronic fatigue rising to 10% along with chemical sensitivity and more noticeable joint and muscle pain and weakness rising to around 5% each. The increase in severity of symptoms for some individuals after exposure had ceased is supported by previously published data. [28]

Importantly the data collated shows that 44% of crews reported immediate or short-term effects, with 63% identifying some form of adverse effect ranging from minor through to incapacitation and 32% reporting medium to long-term effects with 13% no longer able to fly. The majority identified a strong history of exposure and association of symptoms with exposure to contaminated air. Adverse symptoms in flight or shortly after flight pose a serious flight safety risk and are contrary to the aviation airworthiness regulations. [9,35] The difficulties faced by doctors in trying to diagnose ill health, often without awareness of chemical exposure in the workplace, is apparent with strong evidence of misdiagnosis or partial diagnosis. Virtually none of those exposed who presented to a doctor showed their doctor the MSDS or the products they had been exposed to.

Exposure to synthetic jet oils have been acknowledged within the aviation industry to cause a variety of short term symptoms as highlighted on a typical jet oil MSDS. [37,38,39,83,95] Ansett Australia’s expert panel investigating the cabin fumes acknowledged short term symptoms were linked to system defects involving *'predominantly'* oil leakage which was associated with *'irritation of the upper airway mucous membranes, headaches, nausea, lethargy, minor shortness of breath and light headedness.'* [37,96] The airline also advised *'Short term symptoms are not uncomm*on.' [97] This acknowledgement of short-term effects was mirrored by other airlines, the NTSB and others stating:

- *'Oil fumes are detected in minute quantities… and short-term effects, while medically not harmful can cause irritation of the nose, throat, eyes and can cause headaches.'* [38]
- *'Smells and irritants from burning organic compounds from within the engines are known to produce harmful volatile organic contaminants.'* [98]
- *'There are certain instances in which chronic or repeated exposure may sensitise a person to certain chemicals so that later concentrations in the ppb may later illicit an acute hypersensitivity type reaction.' [82]*
- *'The oil may enter the cabin as a mist or vapour… exposure to oil vapour may cause irritation of the eyes and upper respiratory tract. Inhalation of the vapour also gives rise to systemic disturbances such as headache, nausea and vomiting. Exposure to oil mist can produce chemical pneumonitis from direct contact of the aerosol or liquid oil with lung tissue.'* [77]

In fact the BAe 146/RJ aircraft manufacturer advised the Australian Senate Inquiry in 2000 that: [99]

- *'There is absolutely no doubt in our minds that there is a general health issue here. The number of people who have symptoms indicates that there is a general issue... It is very clear that there is an issue here, which needs to be addressed. Our assertion is that it is a health and safety issue, it is not a safety issue... With the weight of human evidence and suffering, which is quite clear, there must be something there.'*

The UK Government studies based on its studies of the oils stated that *'the presence of short chain organic acids was identified, which could cause irritant* *effects'*, [83] while also stating the pyrolysis products of inhaling engine oil could *'exert toxic effects on both passengers and crew'* [83] and a Government report found acute health effects due to contaminated air exposures were *'plausible'*. [6] The Director of the Aerospace Medical Association reported that exposure to VOCs used in aircraft operations can cause skin rashes, pulmonary and CNS symptoms ranging from mild to severe, [2] and many toxic substances including engine oils and hydraulic fluids have acute and long-term effects. [26] At *'temperatures above 320℃ this oil breaks down into irritating and toxic compounds*.' [80]

In 1966 Esso advised that with regard to Esso 2380: [100]:

- *At temperatures in excess of 500-700*^{o}F*, synthetic lubricant 'will probably undergo pyrolysis and release decomposition products of varying degrees of toxicity. Care should be taken to avoid exposures to mists or vapors of oils heated to extreme temperatures... 2380 Turbo oil… may cause skin irritation and dermatitis after prolonged excessive contact… Avoid excessive skin contact and inhalation of mists and vapors released on heating.'*

Further Esso sponsored oil studies [101] exposed animals via inhalation to heated (500^{o}F or 700^{o}F) synthetic oils including Esso 2380. Autopsies revealed *'gross changes suggesting severe irritation of the respiratory tract consisting of edema, inflammation and gross hemorrhage into the bronchioles and alveoli.' The apparent cause of death was deemed a 'result of severe irritation to the respiratory tract.'*

While Mobil reported in 1983 that *'If cabin air becomes contaminated with any lubricant and/or its decomposition products, in sufficient quantities, some degree of discomfort due to eye, nose and throat irritation could be experienced',* [39] the previous and current Mobil Jet oil II MSDSs state:

- *'Overexposure to TCP by swallowing, prolonged or repeated breathing of oil mist, or prolonged or repeated skin contact may produce nervous system disorders including gastrointestinal disturbances, numbness, muscular cramps, weakness and paralysis.'* [95]
- *'Product may decompose at elevated temperatures or under fire conditions and give off irritating and/or harmful (carbon monoxide)*

gases/vapors/fumes. Symptoms from acute exposure to these decomposition products in confined spaces may include headache, nausea, eye, nose, and throat irritation.' [102]

The NTP Chemical repository advises that the effects of TCP, an additive in the lubricant, (CAS 1330-78-5) include: [103]

- *'ACUTE/CHRONIC HAZARDS: This compound is toxic by inhalation, ingestion or by absorption through the skin. It is an irritant of the skin and eyes. It is also an irritant of the mucous membranes and respiratory tract. When heated to decomposition it emits toxic fumes of phosphorus oxides.'*
- *'SYMPTOMS: Symptoms of exposure to this compound include irritation of the skin an eyes, flaccid paralysis without anesthesia, motor activity changes and muscle weakness. It may cause respiratory tract and mucous membrane irritation. It may also cause serious damage of the nervous and digestive systems and muscular pain. Other symptoms include gastrointestinal upset, dis-comfort in distal portions of the arms and legs, soreness, aching, numbness, headache, vertigo, loss of appetite, parethesias and decrease of strength in the arms and legs. It may cause vomiting, diarrhea and abdominal pain... Exposure may also lead to tingling sensations of the hands and feet and cramps.'*

Inhalation of PAN (CAS 90-30-2) an additive in the lubricant is reported to cause short-term effects including: blue lips, skin or fingernails, confusion, convulsions, dizziness, headache, nausea and unconsciousness. Repeated or prolonged contact may cause skin sensitization. [104]

Selected other industry/Government bodies have stated:

- Aero Medical Association, 1953: *Pyrolised oil 'can contain irritant and toxic aldehydes and other dangerously toxic products of incomplete combustion…'* [8]
- USAF, 1954: Oil fogs formed at 400-550°F were 'much less toxic than those formed at 600°F' (in terms of animal time to death); The toxicity of the products arising from the thermal decomposition of the synthetic lubricant was derived largely from the principal ingredient, the base

stock, and only slightly from the mixed TCP isomers, while the products of thermal decomposition were found to be ‘much more toxic’ than the undecomposed (TCP) material. The fogs produced pneumonitis and degenerative changes of the brain, liver and kidneys. [105,106]

- Aircraft Manufacturer, 1962: *‘A small leak in the front compressor section of the engine may allow the lubricant to escape from the engine and pass into the compressor bleed air section where under high compression and temperature the oil breaks down chemically forming toxic compounds, thus contaminating the bleed air going into the cabin.’* [107]
- US Navy, 1965: Inhalation studies of triaryl phosphates found it ‘highly suggestive that components other than ortho tolyl groups have significant toxicity or are capable of synergizing or potentiating other triaryl phosphates.’ [108]
- Oil manufacturer research, 1966: Heated oil studies showed animal autopsies revealed ‘gross changes suggesting severe irritation of the respiratory tract consisting of edema, inflammation and gross hemorrhage into the bronchioles and alveoli.’ [79]
- Aircraft manufacturer, 1966: major contaminants were traceable to lubricating oil leaking into the engine compressor through the bearing seals… the high temperatures encountered within the engine compressor caused the oil vapour to decompose into extremely noxious and irritating substances.’ [109]
- US National Guard, 1977: With regard to inhalation to aerosolized or vaporized synthetic lubricating oils, the ‘oils are subjected to high temperatures and pressures and contact with hot metal surfaces before they are presented for inhalation. These conditions may catalyze reactions that yield toxic products.’ [25]
- USAF, 1979: heated engine oils and hydraulic fluids produced ‘significant quantities of highly toxic compounds.’ [110]
- USAF, 1983: [26] Organic hydrocarbons were mainly identified as causing the fumes/smoke with all of the toxic substances having acute and long-term effects.

- Oil Manufacturer, 1990: ‘It is reasonable to assume that a hazard exists by inhalation of mists or vapors of aryl phosphate esters.’ [111]
- USAF, 1992: Carbon monoxide has a much greater effect at altitude e.g. flight at 6000 feet breathing 50 ppm CO in air results in a physiologic equivalent altitude of 12000 feet. [112]
- HSE, 1998: ‘Repeated low level exposure leads to cumulative toxicity’ and *‘Acute and repeated exposure can produce harmful effects in man, and it has been suggested that chronic exposure at lower doses may cause long-term ill health.’* [113]
- FAA, 1998: *‘JAR-E includes a unique hazard, “toxic bleed air”.’* [114]
- TCP Manufacturer, 1998: *‘Inhalation of the vapours of degrading triaryl phosphate should be avoided as this can result in the short-term irritation of the throat and nose...’* [81]
- UK Government, 1999: *‘The inhalation of mist (containing tricresylphosphate) which can be produced by high pressure systems, or direct contact with the skin, would be hazardous.’* and *‘TCP is toxic’.* [115]
- CAA, 2001: *‘Incidents have been reported of impaired performance of flight crew… events could have been caused by inhalation of agents… leaking from oil or APU and contaminating the Environmental control system.’* [116]
- UK Airline, 2001: *‘DERA Porton Down and BAe Systems have clearly defined that oil leakge/fumes will cause serious discomfort but with no long-term health effects.’* [117]
- Swedish Air Accident Board, 2001: *‘During operation, oil and other contamination in the air that passes through the engine can accumulate in the air conditioning packs and cause a disagreeable odour in the cabin.’* [23]
- Aerospace Medical Association, 2002: *‘VOCs can cause skin rashes, pulmonary symptoms and CNS symptoms ranging from mild to severe.’* [2]

- CASA, 2002: *'It is found that the sound attenuating material used in the air-conditioning ducts can absorb oil and can become a source of persistent air contamination.'* [118]

- Rolls-Royce, 2003: *'Any oil leaking from an engine, entering the aircraft customer bleed offtake, is classified as HAZARDOUS.'* [119]

- Airline, 2003: Acknowledged that it was unable to provide a safe working environment as it could not totally eliminate oil fumes when accepting it *'could not guarantee a pilot would not be exposed to fumes, the likelihood is that the pilot would be exposed to fumes and that therefore there is a risk of damage to his health.'* [120]

- German Regulator, 2003: *'Oil leakage… and oil residues… may lead to harmful contamination of the cabin air and cause intoxication of the flight crew.'* [121]

- FAA, 2003: The forthcoming BAe 146 AD was considered to address *'the possibility of toxic odours and fumes from entering the flight deck or cabin area… which could result in the impairment of flight crew or passengers.'* [122,123]

- CAA, 2004: *'In the event of oil leakage there is the opportunity, therefore, for the pyrolysis products of engine'* and *'lubricant/fuel to enter the cabin air supply and exert toxic effects on both passengers and crew.'* [83]

- CAA, 2004: *'Effect on workers producing tritolylphosphates is characterised by perivascular form of neuritis, and chronic gastritis with deficient secretion, toxic encephalopathy, hypothalamic syndrome, polyneuritis… Does not produce typical syndrome associated with cholinesterase inhibition... Tricresyl phosphate (mixed isomers) Can irritate the eyes on contact, can irritate the nose and throat, can induce nausea, vomiting, diarrhoea, stomach pain and loss of appetite... PAN: N-Phenyl-1- Naphthylamine: Suspect mutagen and carcinogen - tumorigenic in lung, thorax... Octanoic Acid & Decanoic Acid... Severe irritation of eyes and throat and can cause eye and lung injury. Cannot be tolerated even at low concentrations… 4,4'- Dioctyldipheylamine.. When heated to decomposition it emits toxic fumes of NOx.'* [83]

- SAE, 2005: *'Odors are not in themselves hazardous, but intense odors can induce nausea, vomiting and changes in breathing patterns.'* [124]
- BALPA, 2005: International conference conclusion: *'There is a workplace problem resulting in chronic and acute illness amongst flight crew (both pilots and cabin crew)... The workplace in which these illnesses are being induced is the aircraft cabin environment.'* [125]
- TCP Manufacturer, 2005: *'TCP's used in aviation are only classified as Harmful by EU regulations and today, are much less harmful than those used previously.'* [240]
- UK Airline, 2006: If a noxious substance was released into the cabin air system, *'the substance is likely to be irritant rather than toxic.'* [126]
- Swiss Air Accident Bureau, 2006: *'The serious incident is attributable to... the cockpit filled with fumes which caused a toxic effect… caused by an oil leak… The medical examination of the co-pilot... showed that during the flight toxic exposure took place.'* [127]
- CASA, 2007: *'Mobil Jet Oil II- Known to be harmful.'* [128]
- Australian Senator, 2007: *'I am gravely concerned that crew and passengers of BAe146 aircraft have been exposed to dangerous fumes produced by engine defects.'* [129]
- ASHRAE, 2007: *'Typical commercial-grade TCP is a complex mixture of different isomers, all of which are neurotoxicants, with some more potent than others…'* [130]
- Oil Manufacturer, 2009: *'Product may decompose at elevated temperatures or under fire conditions and produce harmful gases or vapours. Vapours or mist of heated product may be harmful by inhalation... R 63.G3 Possible risk of harm to the unborn child. R 62.F3 Possible risk of impaired fertility.'* [131]
- German Government, 2009: *'Does the German Government believe that inhaling of heated engine oil fumes is harmless for the health of crew and passengers?'* Answer: *'No'.* [132]

- Australian Court, 2009: *'Smoke from pyrolysed oil can be hazardous to the eyes, mucous membranes and lungs'* [133]
- AAIB, 2009: *'Oil leakage ...may lead to harmful contamination of the cabin air and cause intoxication ...of the flight crew.'* [134]
- Filter Manufacturer, 2010: *'There is mounting evidence that Volatile Organic Compounds (VOCs) and other aerosolised condensates and vapours related to contamination of breathing air in modern aircraft could have health and safety implications for both the passengers and the aircrew.'* [135]

This survey was undertaken so as to closely look at a group of working and retired or medically retired pilots to see if the trends identified in previous studies would be identified with a larger non self selected group. The UK Government had consistently stated that cabin air contained no substances related to chemical toxicity, there was evidence of occasional irritancy only, no evidence of risk, it was unaware of any long-term ill health amongst pilots and symptoms reported were lesser symptoms with crew impairment remaining low. [83,136,137,138,139] Therefore it was deemed necessary to test this theory, particularly given that incident reports were showing significant crew impairment and exposure, in many cases to more than an irritant. [9,65]

There were inherent problems with the survey, particularly with the problems in getting pilots to speak about medical conditions, the lack of use of common terminology and subsequent identification by the respondents. However this is most likely the most comprehensive survey undertaken to date, over time, looking at health effects and a well-acknowledged workplace problem.

Under reporting in some areas will have been a factor due to unfamiliarity with the terminology such as parathsthesias and chemical sensitivity which the author noted was under reported based on previously identified data from a number of subjects. Additionally as a pilot body, strong supporting medical evidence and documentation was available for many of those reporting ill health, particularly that of an ongoing nature. Given the ramifications of reporting ill health on maintaining a pilot medical certification and employment and the risk of being branded a troublemaker with raising an ongoing issue, there was no benefit in pilots overstating adverse health effects.

Another reason for under reporting symptoms that was clearly identified was the GP and consultant's unfamiliarity with chemical injury effects in addition to the lack of awareness of any potential link between exposure and effects demonstrated by many pilots of some or all symptoms. Therefore various symptoms/diagnosis were in numerous cases not initially disclosed as thought unrelated.

The survey identified that there are significant adverse effects and ill health being experienced by past and present pilots flying the BAe 146/146 RJ. Much of these data are clearly not being advised to the CAA, which is contrary to the aviation regulations, but not surprising given the CAA position of trivializing the risk over many years. This is perhaps because the CAA is fully funded by the airlines that it regulates and is said to not be independent. [140,141,142]

While many epidemiological or case studies may not be able to closely identify the cause and effect, this work environment is different in this respect. In this case there is the situation where oil leaking into the air supply is an acknowledged part of the way the engine operates with large amounts of documented evidence acknowledging oil leaks have been occurring since the aircraft's initial use over 25 years ago. The pilots were well aware of the contaminated air events occurring with 88% reporting exposure, with those who identified frequency, reporting it was a repetitive occurrence. 63% of the pilots surveyed reported adverse health effects, with those who listed specific symptoms (52%), following a clear pattern of neuropsychological, neurological, general, respiratory and cardiovascular symptoms. Those who went on to develop long-term ill health necessitating cessation of flying or developed long-term ill health soon after ceasing flying and reporting symptomology in the above categories to date had generally stayed in the same condition over many years (>15) with some improvement over initial onset, and ups and downs based on avoidance of identified aggravators. A smaller group developed specific neurological conditions or cancer, which appeared to be more likely to occur with time, rather than frequent exposure awareness with ongoing adverse effects. However given that the fumes were seen as normal or a nuisance (acknowledged by aircraft manufacturer) and the fact that contamination was occurring as a function of the use of bleed air, these people will all have experienced ongoing exposures over many years.

Rather than dismiss many individual effects, diagnosis as unrelated or too small to be of importance, it is important to look at the pattern of ill health over the complete group of 274 pilots, most of whom were still working, and look at the pattern, acknowledgments of workplace exposure and published literature and listen to those clinically examining the population and independent expertise.

In an attempt to compare these data to a control comparison population database, the data provided in the current study can be reviewed in an alternative manner. Pilots must adhere to strict medical requirements published by ICAO and enacted into national legislation, [143] however they are deemed to be a healthy working group compared to the general population, [42,144] particularly so given general pilot disqualification may be for effects that would be deemed acceptable on the ground. [42] Some studies have been undertaken on the medical disqualification rate for pilots with disqualification rate of 5.7/1000 pilot years reported for Norwegian commercial pilots, [42] 2.2/1000 pilot years for Canadian military pilots; 4.1/1000 pilot years for USAF military pilots and 1.8/1000 pilot years for navigators respectively [145,146,147] Two US commercial airlines showed disqualification rates in the years from 1975-1982 of 7.75 and 5.77/1000 pilot years. [148] A recent Korean civilian pilot study found 0.6/1000 medical disqualifications with failures categorised in categories not seen in this study. [149] The Norwegian commercial pilot review found 48% of the medical retirements were in the under 40 category, with 52% over 40. [42] Neurological (CNS) causes were identified in the Norwegian study as the major category (with the current medical licensing) mainly in the older age group and based on neuropsychological tests. [42] The current study however found that long-term ill health (permanent cessation of flight) occurred in 75% of those over 45.

It is not possible to equally compare the current study to the above international general medical disqualification studies, however a brief review is worthwhile with a number of assumptions made as shown in Table 4-10.

Table 4-10: Assumptions made in calculations for medical disqualification per 1000 years

Assumptions:
* 11+ years were listed as 13 years (a number were 16/17 years; 6-10 years was listed as 8; 3-5 years was listed as 4 years and 1-2 years was listed as 1.5 years.
** 1901 pilot years (16% undisclosed years assumed to be same average as for those declaring their time on type)

The current study showed of the 274 respondents, 86% (229) provided their years on type* (BAe 146/RJ) which conservatively equated to an average of 6.94 years**. In order to obtain a rough comparison of pilot's who lost their medical certificate/permanent failure of health/cessation of flying in the current study subset, compared to international medical disqualification rates, an additional 10 years flying time was added to the BAe 146 subset. This allows for the fact that some pilots will have flown other bleed air aircraft other than just the BAe 146/RJ. This is generous as 39.4% of the BAe 146 survey pilots had flown 5 years or under on the aircraft and this is thought to be frequently their first jet aircraft flown. The additional 10 years adds 2740 pilot years and provides a total figure of 4641 pilot years. With 36 surveyed BAe 146/RJ pilots deemed long-term unfit (including considered relevant deceased) this equates to 7.8 per 1000 pilot years.

The rate of permanent ill health/loss of flying ability of 7.8 per 1000 pilot years is 37% higher than the 5.7/1000 pilot years found in the Norwegian commercial pilots case and 433% higher than the more recent USAF study reporting 1.8/1000 pilot years. [42,147] Importantly the Norwegian, USAF and other studies reviewed medical disqualification for all reasons, while the current study included only cases thought to be relevant to the contaminated air issue. The alternate Norwegian study found that neurological (mainly neuropsychological in older pilots/possibly related to transition to glass cockpit) findings were the main reason for pilot disqualification followed by cardiovascular (disease/heart attack), musculoskeletal and psychiatry. [42] The USAF study showed coronary artery disease, hypertension, back problems, migraine headaches, diabetes followed by substance/alcohol abuse as the main disqualifying factors. [147] The 1985 US commercial airline pilot study found cardiovascular disease (>50%) followed by psychiatric causes as the most common reasons for disqualification, [148] while an FAA and USAF study found cardiovascular (disease, hypotension), followed by psychoneurotic disorder and cardiovascular and orthopaedic/MS were the main categories respectively. [60,61] Cardiovascular disease has since been reported to be less prominent than earlier studies with better treatment and progressive regulatory criteria. The current BAe 146/RJ study, limited to the relevant categories, does not support these disqualification categories as the study found neuropsychological, neurological, respiratory, and general categories were the most frequent causes.

It is not so easy to compare the rate of ill health to the general population; however the Norwegian study found that the rate of pilot ill health was not greatly different to the general population rate of disability. [42] In addition to the Norwegian study, others also observed that pilots were seen as an exceptionally healthy group, [42,150] however, pilots were noted to be in a better state than the general population but had to cease flying due to strict health requirements, whereas the disease may not preclude a general population ground job. While rates for motor neurone disease were noted to be elevated in pilots, most other diseases were in general lower than those for the US population. [151] Most cancers in general were decreased or similar to the general population. [152,153] Increased rates of brain cancer (glioblastomas, astrocytomas Grade 3-4) in pilots over the general population have been noted in a variety of studies. [150,152,154]

Rates for brain and central nervous system cancers have been reported at 17/100,000 for males aged 60-65 (7 per 100,000 aged 45-49), [155] while the current study reports 2 in 274.

Motor Neurone Disease is thought to occur at a rate of 2 per 100,000 in the population, [156] while the current study reports 1 in 274.

Parkinsonism is reported to occur in 0.9% of people aged 65-69 with Parkinson’s occurring at 0.6% of people in the same age category with prevalence increasing with age (0.01% at age 50) [157]. The current BAe 146/RJ survey reports 1 possible case of Parkinson's in 274.

Corticobasal Degeneration (CBD) is reported to occur at a rate of 4.9-7.3 per 100,000, [158] while frontal lobe degeneration form of alzheimers is said to occur at a rate of 1 case per 200,000 rising to 28 per 100,000 for those aged 60-75. [158,159] The current BAe 146/RJ survey reports 1 case of CBD and 1 case of frontal lobe degeneration in 274.

The main findings of this survey can be summarised as follows:

- Hydraulic fluids and lubricants used in aviation contain toxic hazardous chemicals which can be toxic and irritating;
- Exposure to such substances and their pyrolysis breakdown products can produce symptoms of toxicity and irritation;
- There was a very high awareness level of exposure to contaminated air;
- Ill health occurred with a strong exposure history and short term symptoms or short-term developing into medium to long-term. Additionally a significant number of crew reported a general awareness of symptoms in conjunction with seeing fumes as regular and normal, with long-term health effects then reported;
- The pattern of chronic ill health shows a direct correlation with contaminated air exposures and follows an identifiable cluster of symptoms. The data showed that frequency of exposure was more likely to lead to chronic effects than one off big exposure events, however both situations were possible. The cluster of symptoms are identified as:
- Symptoms of neurological dysfunction that are occurring during or immediately after exposures include: tingling, tremors, shaking, parasthesias, vertigo, grey-outs and balance problems with some going on to become more debilitating in the long-term;
- Symptoms of impairment to neuropsychological function including intense headaches, performance decrement, memory impairment, dizziness, confusion and disorientation immediately after exposure and in

the short-term with an ongoing longer-term problem emerging including altered co-ordination and depression;

- Symptoms of upper airway and eye irritation, breathing, cardiovascular and vision problems are reported immediately after exposure and in the short-term with respiratory problems, cardiovascular and skin problems continuing on a long-term problem;
- General symptoms of fatigue and exhaustion and nausea are the main immediate or short-term symptoms with an identifiable pattern of exhaustion, chronic fatigue chemical sensitivity and joint, muscle pain and weakness becoming apparent in the long-term.
- A smaller but identifiable number of people developed a range of more debilitating neurological conditions including: 'possible' mild Parkinson's; Alzheimer's, Corticobasal degeneration, MND as well as cancers including stage 4 GBM brain tumours;
- Additional diagnosis identified after completion of survey combined with strong history of short and long-term identified pattern of symptoms and exposure history, included Goodpasture's Syndrome and MI;
- Misdiagnosis or difficulty with diagnosis and limited testing undertaken was common;
- Significant extended time off work was identified as occurring with pilots reporting serious ill health but able to return to work in the long-term. 13% of pilots were unable to return to flying at all or developed long-term ill health soon after ceasing flying;
- The symptoms identified present a significant immediate and short-term health problem, which is contrary to aviation regulations, while a significant long-term health trend is evident. Pilots should present with less ill health than the general population, however this is not the case;
- A further full scale and detailed case controlled survey should be undertaken by an independent occupational physician and epidemiologist in such a way that accurate data can be provided by pilots without fear and free of interference from potential commercial or political interests;

- There is great fear amongst pilots in raising this issue with subsequent ongoing risk to flight safety and health. There is a great lack of understanding of the real implications of continuing to fly with ongoing exposures. There is an overall feeling that the problem has gone on so long and cannot be fixed, necessitating the crew to endure the situation to maintain job security in conjunction with either ongoing adverse health effects or degradation of health over time as the only option.

Conclusion

The BAe 146/RJ pilot health survey is an in depth, non-self-selected review of health effects being experienced by current pilots, and medically retired or retired/deceased pilots reporting adverse effects of an immediate and short-term nature through to long-term. The high levels of health effects must be reviewed in terms of acknowledgement that oil leaks are occurring on this aircraft type as a function of the way the aircraft is designed and operates; extensive industry data showing that oil leaks are occurring and the disincentives for pilots to report adverse health effects. There is extensive evidence showing that oil fume events are occurring and are significantly under-reported.

This is a much hidden issue that is clearly making pilots choose between operating the aircraft, often contrary to aviation legislation (FAR/EASA 25.831 and fitness to fly) and maintaining employment and a pilot licence verses flight safety and particularly pilot health. This has serious implications for the health of all cabin occupants. The industry failure to appropriately recognise the conflict between corporate objectives and flight safety and crew health has allowed this problem to remain unaddressed, however this is not a new problem. [160]

The pilots have identified in this survey, the industry and human conflict, as well as in some cases their own union’s inability to address the problem. The scale of the problem identified here, along with other surveys and available data indicate that in order to rectify the problem, truly independent expertise, free of commercial considerations such as possibly the military, is required to review the data in addition to carry out an advanced case controlled study or epidemiological review such as that undertaken in the case of the US Gulf War Veterans. Flight safety is being significantly compromised and there is extensive ill health both on a short and long-term basis, which is occurring in a safety critical and highly medically scrutinised cohort. The rate of ill health is clearly above what is expected in a pilot population.

4.3.5 Discussion: Ill Health in Aircrew

Ill health in aircrew from three surveys

The three health surveys undertaken by the author over a ten year period show a very similar pattern. While the original Australian BAe 146 survey covered only 21 pilots, it identified the same trends being seen on the other side of the world in a larger group some 5-10 years later. [47,49,59]

The three surveys show remarkable similarity with all showing a strong correlation between exposure to contaminated air and adverse effects. The crew ill health cannot be seen as a normal workplace or general background population trend. There is nothing to be gained for a pilot to acknowledge ill health, given the industry longstanding views that ill health is not linked to acknowledged fume events and the risk to medical certification and employment in a narrow skilled area. When asking for crews to participate in the surveys, the author received numerous comments from pilots such as:

- *'I'm not sure of the consequences of completing the survey right now due to identification of respondees relative to jeopardizing their aeromedical qualifications (i.e., identifying some or any of those symptoms or ailments which may not have been reported to flight surgeons on official documents).'*

Therefore when dealing with a safety critical role, the remarkable juxtaposition between occupation and health cannot be dismissed. It must be noted that pilots, particularly the captain, are entrusted with multimillion dollar equipment and countless lives and should not be seen as malingering, simply because there is a conflict between corporate objectives and identifying a safety and health issue that is related to all who breathe the same air in aircraft.

The adverse effects being reported, considered by some to be very broad, are in fact categorised into a pattern of symptoms in a number of body systems, including the nervous and neuropsychological systems, respiratory, cardiovascular, gastrointestinal and likely the immune system. The symptoms can either be expressed specifically to these systems or can be expressed more generally as chronic fatigue, headache, weakness, sensitivity or behavioural change.

While the former two surveys used self selected pilots, most of whom were current crew, the later 2009 BAe 146/RJ survey was not self selected and therefore will have experienced a greater likelihood of resistance to provide accurate information. However, in all cases, the same pattern of adverse effects were seen in moderate but concerning rates in the immediate to short-term such as performance decrement, intense headaches, irritation, memory impairment, dizziness, breathing, vision and fatigue right through to tingling, intoxication and loss of consciousness. These present major flight safety issues and are contrary to the airworthiness regulation FAR 25.831 prohibiting undue discomfort and fatigue related to contaminated air. Unlike a general occupational workplace, aviation, despite acknowledged under-reporting of contaminated air events, is highly regulated. It is acknowledged that oil leaks occur as a function of design and operation of using bleed air to supply the cabin air, along with ongoing maintenance issues that allow such exposures to occur. There is a vast amount of industry documentation regarding hydraulic fluid and particularly oil contamination of the bleed air supply and including reports of exposure events in many (but still limited due to under reporting) cases. Awareness of such exposures is not limited to the civilian aviation industry nor to particular aircraft or airlines. A growing number of industry and Government bodies are starting to recognise that breathing oil and other similar contaminated air in aircraft is hazardous and harmful as already discussed.

What became particularly apparent in the two BAe 146 surveys was the development of a long-term pattern of ill health involving many of the short-term effects worsening over time, along with the development of additional longer-term symptomology. The B757 survey, at the time, did not show the long-term effects to the same degree; however the long-term B757 symptomology has since been recognised along the same lines as the BAe 146/RJ. Long-term effects are categorised as being neurological, neuropsychological, respiratory, cardiovascular, general and gastrointestinal with an emerging trend of more serious neurological, autoimmune conditions, selected cancers together with a pattern of misdiagnosis or partial diagnosis.

While more serious neurological conditions, autoimmune diseases and cancers could easily be dismissed as insignificant it is necessary to look at:

1) the exposure history;

2) the entire study group;

3) published literature related to chemical exposure; and

4) industry data acknowledging leaks and hazards.

Upon doing this a more sound judgment by the appropriate people can be made.

Frequency of exposure or ongoing residual or regular exposure was highlighted as more of a problem than one off higher level events in most cases. What is emerging is that while many pilots simply will not discuss health effects associated with a problem they consider is ongoing and unfixable, some will suffer mild or no effects while a majority are reporting varying adverse effects, falling into the same pattern associated with exposure to contaminated air in aircraft (oil and hydraulic fluids). The syndrome presented here may be reversible for most in the short-term, but what is evident is that a chronic syndrome following repeated or in some cases significant single exposures is occurring along with selected long-term specific conditions that should be individually assessed, based on the above suggested basis. A considerable number of individuals are experiencing a similar pattern of symptoms along the line of the short-term effects but extending in duration to the long-term, with well above population or workplace averages and no longer being able to maintain their medical certificate to fly. All declared medium or long-term effects should be documented as part of a pilot's medical certification. Additionally, the short-term effects being commonly reported are acknowledged as being linked to leaking oil and hydraulic fluids by authoritive bodies in the aviation industry itself. What is denied is the link to long-term effects; however the pattern of short-term effects becoming long-term is clearly evident.

A UK Government committee inappropriately dismissed chronic effects, suggesting there was *'insufficient evidence to recommend any specific additional research for any other acute or chronic health effect with regard to oil/hydraulic fluid contamination incidents.'* [6] This was based on '*the lack of* *studies specifically designed*' to address the question of whether ill health was occurring to warrant further research '*systematically*'. [6] The evidence available was deemed descriptive and anecdotal that did not *'meet the standards of a properly designed epidemiological study.' It was considered that some of the chronic effects being reported were similar to those seen in healthy individuals (given placebos) in indoor trials of air quality.* [6] This study was strongly criticised [161] and as previously shown, it is necessary to look at the total evidence *'appropriately'* in order to reach a correct conclusion of whether further research is required.

There is a lack of understanding by the crew of the implications of exposure to contaminated air in both the short and long-term along with either a poor understanding of the medical effects or corporate bias being shown by medical examiners such as company refusal to allow a pilot to talk to a doctor after a significant exposure event, suggesting there were *'too many contaminated air* complaints and all being somosomatic.' [65] A pilot reported that *'When I've raised the issue with my GP he didn't know where to take it and the CAA medical department did not appear convinced,'* a common theme amongst pilots recorded by the author. Safety of flight is not taking into consideration crew adverse effects, despite contaminated air being a direct airworthiness issue, as the aviation industry views the definition of aircraft safety is that unless an aircraft crashes for technical reasons, it is deemed safe. [99] However acknowledgement by the BAe 146 manufacturer that adverse effects can occur in conjunction with oil contamination can be found in its own publications as seen in Figure 4-16 and the admission by BAe that: [99]

- *'There is absolutely no doubt in our minds that there is a general health issue here. The number of people who have symptoms indicates that there is a general issue... Our assertion is that it is a health and safety issue, it is not a safety issue... With the weight of human evidence and suffering, which is quite clear, there must be something there.'*

Adverse effects from contaminated air are known to have been first highlighted in 1952/1953 with an in flight report linking incapacitation to exposure to synthetic jet engine oil in 1977. [8,25,162] The problem still remains unresolved some 58 years later.

Other data

The author has undertaken a brief review of the health being experienced by other current and former BAe 146/146 RJ pilots internationally.

While a number of the Australian former BAe 146 pilots including the author are publicly acknowledged as having lost their medical certificates to fly after some years operating the BAe 146, [34] a similar pattern of ill health is now emerging in Europe.

The pattern emerging is almost identical to that shown in the UK 2009 BAe 146/146 RJ survey and other surveys undertaken by the author.

While the numbers in each country could be dismissed as non-representative, the trend is what is important. Ill health and or loss of medical certification are also being reported in relation to BAe 146/RJ operation by pilots from Sweden, Belgium, Germany and New Zealand. It has taken time for these data to emerge, mainly due to lack of awareness and isolation together with an industry in denial.

The best example is for the Swedish BAe 146 captain in the 1999 Malmo incident [23,91,92] who gradually had to reduce flying duties over the years until he could no longer fly at all and now suffers the same pattern of ill health identified in the surveys identified by the author.

The symptoms identified in Swedish cohort range from grade 4 GBM (age under 45), colon cancer to clinically identified mild Parkinson's symptoms (age under 55), ectopic heartbeat, melanoma leading to brain tumour and the generally identified less severe but ongoing symptomology with the same pattern identified in the present study and with the same exposure awareness. The same pattern of neurological, neuropsychological, respiratory, general and cardiovascular symptoms, are being seen elsewhere in the other international BAe 146/RJ pilots. There was less awareness in the United States with great fear of talking about the issue of fumes seen as: *'tolerated as cost of the job'.*

Figure 4-16: BAe SIL: 21-146 - Cabin Air Quality Question

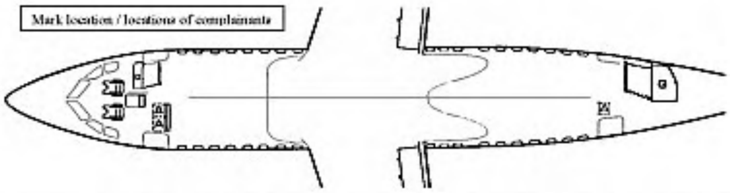
SERVICE INFORMATION LEAFLET
21-146-RJ-536-1
CONTINUED

Attachment 2 – Cabin Air Quality Question (Continued)

Reporter Details - complete additional sheets for different people

Crew / Passenger	Male / Female	Approx age:-	Smoker / Non-smoker	Assessment of fitness: Good / Ave / Poor
Did you take any over-the –counter medication	analgesics	decongestants	Other:-	
Are you taking any prescription medication if so what	No / yes details:-			

Location in Aircraft



Phase of flight	start	taxi	climb	At switch from APU to engine air	climb	cruise	descent	At switch to APU air	descent	Land & taxy

Symptoms	*The following reflects a range of possible symptoms, which might arise in a variety of circumstances, as well as individual terms used in previous reports. For __each__ category, circle 'normal' __or__, all relevant 'descriptions' __or__, add a new description. Note that individuals may only show one or two symptoms in total, in this case, please indicate by circling 'normal' or ' none' as appropriate.*								
Head	normal	headache	light-headed,	pressure in head,	'moon-walking'				
General	normal	dizzy	faint	giddy	vague	lack of concentration	poor co-ordination		
Alertness	normal	fatigued	tired	sleepy	somnolent	exhausted			
Emotions	normal	relaxed	euphoric	elated	'drunk'	intoxicated	irritable	morose	pugnacious
Eyes	normal	dry	irritated	burning	streaming				
Nose	normal	dry	irritated	burning	streaming				
Throat	normal	dry	irritated	burning					
Breathing	normal	shortness of breath	breathless	laboured breathing	rapid breathing	pressure in chest			
Stomach	normal	nauseous	vomiting						
Numbness or Tingling	none	scalp	hair-roots	nose	lips	fingers	toes		
'Blueness'	none	lips	nail-beds	finger-tips					
Any other comments Consider general health									

Smells or Visible Fumes

Describe anything smelt or seen	

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BAE SYSTEMS Regional Aircraft, Prestwick International Airport, Ayrshire, United Kingdom
Telephone +44 (0) 1292 675278 Facsimile +44 (0) 1292 675432

Three out of four Australian female BAe 146 pilots, who were recognised in flights of interest (1st all female Ansett regional crew, 1987 and 1st all female crew in the Qantas (including the author) regional network [163,164]), were subsequently unable to continue to fly, with loss of their pilot medical certificates following some years of repeated exposure to contaminated air on the BAe 146. [34] The fourth pilot never flew the BAe 146. The author has sighted in the surveys identified here, the medical reports of the other two pilots (as well as the author's) and acknowledges they support the same pattern of exposure as the main group of pilots who have lost their medical certificates. Ill health has been ongoing for 16 years for one and 14 years respectively for the other two. The flight safety effects evidence in one of these cases preceding loss of flying certification was reported as the *'Brisbane incident'* with the pilot experiencing *'a feeling like drunkenness (with) difficulty lining the aircraft up for landing'* and unaware of the extent of incapacity. [34]

The author has undertaken a brief review of medically retired Boeing 757 pilots. 23 pilots were contacted (or details were provided) and asked to undertake a brief questionnaire along the line of the BAe 146 printed format. They showed a pattern of ill health again along the same line as the BAe 146 pilots. While the original 2001 B757 survey [49] did not identify the longer-term trends to the extent that the BAe 146 surveys have, this pattern has now been reversed. Of the 23 pilots identified most appear to follow the same pattern with a history of exposure, given they flew on B757, mostly with an operator, British Airways, that publicly, acknowledged oil leaks were being reported. [6] B757 pilot medical retirements were identified in the UK, US and Holland. Three cases of Grade 4* GBM (*1 stage 3/aggressive/regarded as 4) were reported (under 47, 52, 65 years), 1 colon cancer, 2 cases of Parkinson's (at least one acknowledged by doctor to be related to oil fumes, age under 45) and 2 other cancers (one skin) along with the majority following the same pattern of symptoms – neuropsychological, neurological, general, gastrointestinal, respiratory, cardiovascular. British Airways advised that two of its B757 pilots reported more oil fume reports than any other pilots (34% of the oil fume ASR reports). [165] The two pilots concerned were the subject of numerous fume event reports, including an AAIB report of fume events over 3 days which identified hydraulic fluid and oil fume contamination. [166] One of the pilots subsequently died of Grade 4 GBM in 2009, while the other was medically retired with the clearly identified pattern of symptoms after the oil additive TCP was found in his blood. [85,167] Both pilots were in their mid forties.

The 23 Boeing 757 pilots identified, while mostly British, were also from the US and Holland with a number of them in their 30's and 40's. Statements made by these pilots include *'management advised as the aircraft had been previously stored in the desert, the regularly reported smell was a dead desert rat'; 'the sweet sweaty sock smell was hardly ever written up as all aircraft did it'* and that *'the long-term symptoms were so bad that the former pilot could not walk at the time and had trouble self feeding.'* Almost all these B757 crew will have extensive medical reports as almost all had lost their medical certificates to fly. The general diagnosis ranged from CFS/ME and sensitivities to chemical poisoning, autonomic nervous system and cognitive problems, neurological chemical injury at work and OP poisoning. Others with similar symptomology were reported to the author, however no recent contact was possible and therefore they have not been included in this sample. The airline industry input into this debate can be evidenced with the response given to a GP who had requested a TCP blood test on behalf of his patient (one of the above pilots):

- *'The evidence for aircrew ill health due to contamination of the cabin air is being systematically reviewed by the Health Protection Agency and Dept of Health. It is considered too early to blame any particular substance, notably TCP and heavy metals… It is not possible to objectively choose an analyte or interpret its level in the body without this.' [168]*

The HPA and Department of Health review mentioned refers to the UK COT committee report, which found short–term effects were plausible, but ruled out any link to the contaminated air or any long-term effects. [6]

A health survey, which has not yet been published, undertaken by a former UK aircrew member, collated data from 910 self selected aircrew (96% cabin crew from one UK airline/4% pilots) via a written on line survey. [169] Although the research was not complete as of mid 2010 a wide range of symptoms were being reported which appeared to follow the same pattern as those identified by the author. These include:

- *'I have been suffering with many of these symptoms over the past 3 years especially. The company I work for are constantly telling me that I am the only one with a problem, but I know of others who are too afraid to speak out. Two flight crew were incapacitated recently. My GP is worried for my health. I was made an example of last year as I kept* *reporting problems and submitted an Air Safety Report. This led to me being grounded for 6 months as a warning to the other crew to keep quiet! Also, the flight crew will not put anything to do with fumes in the tech log.'*

- *'All my allergy and auto-immune tests have come back negative. My Consultant says he believes I am an "intrinsically healthy person" and all my health problems have been caused by "external factors." My GP believes all my health problems have been caused by flying and has written Aerotoxic Syndrome on my medical certificate. I have been on sick leave for over a year and XX has threatened to terminate my contract on 3 occasions...'*
- *'I had toxic fumes on the Airbus 319 about 3 years ago, did not know what it was at the time till I saw a program on toxic fumes, had all the symptoms, sore eyes, nausea, hard to breathe, flight deck on oxygen feeling the same, company telling us if symptoms continue to go to hospital. Found out later that it was fumes from the oil filter (told by my manager.)'*
- *Pilot reported was getting more and more tired while flying the XXXXXX (sweaty socks) to the extent of feeling like hitting the wall with no will to continue or take any further part in the flight... Symptoms xxx, xxx, drove down wrong side of road twice after filling car with petrol… airline claims to have no idea of what causes sweaty socks in the descent and rebuts all consideration of OPs... still flying although airline knows pilot claiming to be poisoned by OPs.*

While not all respondents reported the cabin air quality as the cause, there was a high rate of reported adverse effects including upper airway irritation, fatigue, neuropsychological, neurological, respiratory and cancer above the national average with supportive diagnosis in many cases.

Significant ill health with loss of pilot medical certification with the same pattern of illness and a history of exposure to contaminated air identified in most cases was also reported by pilots on other aircraft types including the B747, B777, B767, B737, F70, F100, A320, EMB 120, Dash 8, C130 amongst other aircraft types. Cabin crew were certainly reporting ill health with a similar pattern of effects as well as loss of health reported by coastal surveillance personnel with a history of exposure to contaminated bleed air. In a documented contaminated air event on an A320, a cabin crew member was subsequently diagnosed with a parotid tumor, a rapid growth (grade 1) tumor in the right frontal lobe of brain and other rapidly growing tumors requiring removal as well as a growth in one eye. One of the other cabin crew also involved in the same event, was subsequently diagnosed with rapidly growing growths in 2 distinct locations.

In addition to the identified pattern of neurological, neuropsychological, respiratory, cardiovascular and general effects, a number of other findings stood out (that were also seen in the BAe 146 surveys and B757 review) including; epilepsy, nickel or beryllium adducted to DNA or identified, reduced mitochondrial ATP levels and conversion efficiency, TCP positively identified in pilots, reduced superoxide dismutase Zn/CU-SOD gene expression and liver function abnormalities. [170] Upon review of the documentation available, it is clear that medical effects and diagnosis are supported by a range of tests, that appear to fit into a consistent pattern. The tests that the author has cited or been advised about on a routine basis include: respiratory, neurological, neuropsychological, cardio, autonomic, chronic neurotoxicity blood pathology, brain imaging scans (SPECT, PET, MRI, MRS, EEG) amongst others. [170]

4.3.6 Discussion: Published Evidence

There is a growing amount of published and other data that specifically support the health effects observed in aircrew is related to contaminated air events. [170] These can be broken down into specific areas including:

Neuropsychological effects

In 2002 and 2006, assessments of 8 (2 pilots) aircrew and 27 pilots respectively, were undertaken. [171,172,173] Evidence was found of ‘under-functioning on tests associated with psychomotor speed, executive functioning and attention’. [173] The findings of ‘significant impairments’ on tests of reaction time, information processing speed and fine motor skills among the majority of testees were said to be consistent with other studies carried out in occupational settings where organophosphate and solvent exposure took place.

[171,174,175] Neuropsychological abnormalities occurring as a long-term result of acute OP exposure was recognised by the UK Government in 1999. [176] A recent study involving OP exposures *'suggest a relationship may exist between low level exposure to organophosphates and impaired neurobehavioural functioning and these findings have implications for working practice and other occupational groups exposed to OPs such as aviation workers and Gulf War veterans.'* [177] The UK COT committee investigating OPs found that *'The balance of evidence supports the view that neuropsychological abnormalities can occur as a long-term complication of acute OP poisoning, particularly if the poisoning is severe. Such abnormalities have been most evident in neuropsychological tests involving sustained attention and speeded flexible cognitive processing ("mental agility").'* [178]

Respiratory effects

Respiratory disease was reported in 14 (4 pilots) BAe 146 aircrew with all developing respiratory complaints consistent with lung injury as a result of exposure to, and inhalation of hydrocarbon aerosols during flight. [76] Symptoms reported included breathlessness, cough, wheezing with findings including abnormal pulmonary diffusing capacity, reduced oxygen tension, widened arterial oxygen gradients, non specific inflammatory changes and a nodular infiltrate, abnormal DTPA lung clearance studies and granulomata. Diagnoses given by doctors included asthma, Reactive Airways Dysfunction Syndrome (RADS) and alveolar/Interstitial lung injury. The lung is *'particularly suitable for the uptake of gases and is prone to the development of disease as a result of deposition of particulates and absorption of volatile compounds that may cause injury'.* [76] Lung diseases may involve any part of the respiratory tract and *'may not be reversible.'* [76,179] Additionally according to Mobil, *'malignant lesions which might arise from inhalation and subsequent swallowing of oil mists could be expected to occur in the respiratory and gastrointestinal systems.'* [180] While oil mists are aerosols produced when oils under pressure are released into the air or vaporized and then condensed in the atmosphere, the mists being respirable or particulate mater (<0.5 microns) can reach the lungs. [180] Particles can therefore condense in the nasal and bronchial passageways, however, Mobil suggested such effects could only occur in metal working environments rather than accidental intermittent mist release. Occupational exposure to low levels of OPs and or solvents can result in restrictive lung dysfunction. [181] Essentially, many inhaled toxins are capable of producing illness either through direct pulmonary damage or by their systemic toxicity for which misdiagnosis or maltreatment are likely when obvious historical evidence or heightened suspicion for acute inhalation exposure does not exist. [182] Pulmonary damage, which includes direct pulmonary injury and pulmonary sensitization, occurs most commonly after the inhalation of respiratory irritants including those that induce immunologic reactions. Systemic toxicity occurs most commonly after the inhalation and absorption of asphyxiants, OPs, volatile hydrocarbons and metal fumes. [182]

Neurological effects

Wide variations in response to exposure events occur, most likely due to variations in individual susceptibility, however neurological symptoms are reported in most cases. [63]

Toxic encepaholapthy

Twenty-six MD80 flight attendants who had been exposed to aircraft contaminated air were diagnosed as having Toxic Encephalopathy based on neuropsychological examination and Position Emission Tomography (PET) functional brain scans. [183] *'When examined for Neurotoxic injury with a sophisticated approach (SPECT, PET neuropsychological evaluation and so on) profound impairment can be documented.'* [183,184]

Chronic neurotoxicity

Eight pilots were assessed for the presence of autoantibodies against selected proteins (NFP 200; MAP 2, TAU, MBP and GFAP) used as biomarkers for central nervous system injury. [185] The finding of *'increased autoantibodies against nervous system proteins in the flight crew is consistent with neurological deficits and, in the absence of other neurological diseases, it is concluded that it is consistent with chemical (such as TCP) induced nervous system injury.'* [185] Additionally *'OPICN induced by low-level inhalation of organophosphates present in jet engine lubricating oils and the hydraulic fluids of aircraft could explain the long-term neurologic deficits consistently reported by crewmembers* *and passengers, although organophosphate levels may have been too low to produce OPIDN'.* [186] OPICN encompasses structural, functional, physiological, neurological and neurobehavioral abnormalities. [185]

Autonomic dysfunction

A similar unique pattern of autonomic dysfunction was found in aircrew to that of selected sheep dip farmers with long-term neurological sequelae resulting from acute organophosphate intoxication or repetitive low-level exposure to such compounds. [187] *'Neurological sequelae of long-term exposure to OP consist of a patchy pattern of dysfunctions of the autonomic target organs situated in the skin, in large blood vessels and in the brain. Cholinergic functions are selectively preserved while monoaminergic functions deteriorate in the brain and the skin. Distal somatosensory neuropathy is the predominant somatic nerve dysfunction associated with chronic exposure to OP. The central somatic conduction pathways and the cranial nerves are resistant to the neurotoxic effects of chronic exposure to OP. These neurological sequelae can explain the symptoms and ill health in patients with chronic exposure to OP.'* [187] Significant Autonomic nervous system dysfunction including abnormal heart rate variability has been reported in Gulf War veterans. [188,189]

Assessment

There is a pressing need for internationally recognised medical protocols to evaluate ill health following exposure to aircraft contaminated air including psychological, neurological, neurophysiological assessment, neuroimaging and respiratory testing. [190] Diagnosis such as industrial hysteria or psychosomatic disorder were deemed unhelpful and misleading. [190] *'Organophosphate poisoning (aero toxic syndrome)'* was recognised as possibly being *'a very significant factor in pilots who develop psychological symptoms'*, that did not fit the *'classical stress'* pattern with such findings met with total resistance from referring doctors. [191]

General effects

Reported symptoms associated with contaminated air exposure events and flying are not new and have been published over the years. [19,21,26,28,47, 63,192,193] A 2008 FAA funded study [193] found that out of approximately

4000 US cabin crew, 17% and 21% reported neurological and respiratory work related illness respectively in the previous year, with notable rates of adverse effects experienced in the previous week as noted in Table 4-11 in section 4.3.7. The studies could be criticised for not following traditional epidemiological practices. However, the case studies and surveys show the only available independent data describing health effects in aircrew related to exposure to cabin air and contaminated air events are in the majority of cases directly related to smoke and fumes (predominantly oil/hydraulic fluid related) in aircraft. Health effects are not limited to aircrew and have been identified as a passenger issue as well.

A 2005 study found that the histories of 38 aircrew *'were remarkably consistent with the reporting of events and symptoms, and there was a definite temporal relationship between the onset of symptoms and exposure history'* with both short and long-term symptoms reported. [192]

In a study of 60 aircrew (39 pilots) *'work capacity was affected and 35% of crew reported they were chronically unfit to fly'*. [63]

Other studies as far back as 1983 associated flight attendant reported symptoms (upper airway, chest, CNS) with the *'dirty sock odour'* and the use of *'Mobil Jet Oil II'*, with the airline involved also suspecting *'Mobil Jet Oil II to be the culprit'* and *'destructive analysis of Mobil Jet Oil II'* recommended. [194,195,196,197]

In 1999 Dr Cone advised that *'Contamination of APUs by engine oil was recognised over 15 years ago as a cause of symptoms among flight crews.'* [196]

In 2008, the FAA published a detailed medical protocol specifically related to exposure to aircraft bleed air contaminants among airline workers. [198] This protocol listed limited case studies, short and long-term symptoms and selected exposures and documented health effects.

Other data

Damage and dysfunction to the brain are noted in fatigue and pain-cognitive illnesses with identified brain imaging techniques identified. [199] Brain SPECT scans had been previously identified as a highly sensitive diagnostic method in investigating OP effects on the brain. [200] The symptom complexes of Gulf war veterans show some overlap in symptomology and brain imaging abnormalities with other medically unexplained illnesses such as chronic fatigue syndrome, fibromyalgia and other chronic pain states. [201] While strong evidence linking pesticide use with GWI and a possible association between low level nerve agent exposure and GWI has been reported, [188] brain imaging techniques including a pharmacologic challenge provide differing neuropathologic bases for Gulf War Illness. [201] Gulf War illness, which has received extensive recent research at the direction of the US Congress *'is associated with diverse biological alterations that most prominently affect the brain and nervous system. Research findings in veterans with Gulf War illness include significant differences in brain structure and function, autonomic nervous system function, neuroendocrine and immune measures, and measures associated with vulnerability to neurotoxic chemicals.'* [188]

Neurological illnesses such as Parkinson's are linked to hydrocarbon solvent exposure, [202] while increased levels of Parkinsonism with occupational exposure to pesticides, supporting a *'toxicant-induced cause of Parkinsonism.'* [203] Raised levels of MND in both pilots and individuals with neurotoxin exposure have been published. [150,151,186,188,204,205] Additionally, an association between MS like symptoms and diagnosis have been identified with exposure to triarylphosphates. [206] Such substances were proposed as a plausible etiological agent in MS clusters. [207] Off shore oil workers and other Aero Derivative Engine workers in Norway working on the turbine engines, which are being used principally for power generation and whuch use the same synthetic oils, are being reported to be suffering from neurological illnesses including MS. A similar pattern of symptoms reported in aircrew. [208,209]

Higher rates of brain cancer have been noted in pilots as well as Gulf war veterans *'potentially exposed to nerve agents'.* [150,151,188] Additionally, increased rates of colon cancer, cancer of the buccal cavity and pharynx and diseases of the nervous system and sense organs have also been suggested. [150]

The RAAF recognised that *'Most of the contaminants enter the body through inhalation, and many are highly toxic, even in extremely small amounts. Short* *term exposure may cause irritation of the respiratory passage, cough, shortness of breath, light-headedness, dizziness, and confusion. Skin irritation, nausea, abdominal cramps, and vomiting may also occur. There is some evidence that continued exposure to small amounts of certain contaminants may produce chronic, long term, and irreversible damage to humans. Blood disorders, and damage to lungs, liver and kidney may occur. Some toxins may be potentially carcinogenic.'* [210]

Repeated low-level exposure to organophosphates leading to cumulative toxicity and long-term ill health has long been recognised. [113,211] Some studies have suggested that long-term effects on the central and peripheral nervous systems may be associated with frequent but low level exposure to organophosphates. [212] The neurological effects were different from those associated with delayed neuropathy associated with acute OP poisoning. The new neurotoxic effects ranged from neurobehavioural and electroencephalographic changes, neuromuscular electrophysiological changes and neuropsychiatric disorders. [212] Residual central nervous system dysfunction from long-term exposure to organic solvents amongst aerospace workers persisted years after the end of exposure. [213] There is considerable evidence supporting that long-term excessive occupational exposure to mixed organic solvents can cause a wide range of chronic CNS abnormalities. [213,214] When solvents are used in mixtures or contain impurities, the effects may be additive, synergistic or potentiated. [214,215] The more severe cases of encephalopathy associated with chronic exposure to solvents are characterised by mild to moderate degrees of cognitive impairment and are distinguished from other neurodegenerative diseases such as Alzheimer's or Parkinson's by the static nature of cognitive impairment and possible selective improvements in neuropsychological functioning if solvent exposure is discontinued. [213] Career long exposure to solvents could have greater clinical importance in later years of life than during the years of active exposure, given increasing age related neurodegeneration. [213]

Expanding the identification and characterization of biomarkers beyond BChE is necessary for detecting and treating poisonous OP exposure. [216] A recent study has found that toxic gases or oil mists in cabin air may form adducts on plasma butyrylcholinesterase and albumin, detectable by mass spectrometry. [217] Exposure to TCP isomers in the jet oil leaking into the air supply is thought to be the leading cause of *'Aerotoxic Syndrome'*. In the past, diagnoses of incidences of poisoning from the active metabolite of the ortho TCP isomers, CBDP have relied on clinical symptomatology and epidemiology, with successful diagnoses generally only made after severe widespread high dose exposure. *'If Aerotoxic Syndrome is in fact caused by CBDP, the levels of exposure are probably relatively low, because the symptomatology is different from the paralysis observed on high dose exposures.'* [217] The individual susceptibility is hypothesized to occur most likely due to the interindividual differences in OP metabolism by cytochromes P450. [217] Low dose exposure therefore requires a sensitive means of diagnosis. [217] Mechanistic studies have suggested that long-term-effects may be mediated by cholinergic mechanisms or phosphorylation of neuronal proteins. Other mechanisms may also contribute to differential sensitivity as genetic differences in detoxification enzymes and non-specific binding account for some of the variations between people, [212] supporting that the consequences of long-term exposure to OPs are influenced by genetic components. [178] It may be that epidemiological techniques are yet not sufficiently sensitive to identify susceptible people. Mechanistic research may identify more clearly the pathophysiological effects that can be investigated in individuals and may be informative for future epidemiological studies. [212]

There is limited evidence that exposure to certain pesticides (including organophosphates) may compromise the immune system. [218] In 1992, preliminary studies on TCP found that the 'immune system may be a sensitive target for TCP'. [219] Other immunotoxicological studies have provided evidence that chronic exposure to certain chemicals can directly effect the immune system in vitro; some in an immune suppressive manner and some in a potentiating manner. [86] For example hydrocarbons have been implicated in cases of Goodpasture's syndrome. [86] Irritation to the immune system and subsequent health effects is an important consideration. Therefore exposure to chemicals such as those used in aircraft should be considered when seeking medical care for a number of conditions, rather than simply dismissing something as unrelated, as the information could be beneficial and vital to eliminate the risk for others.

It is reported that OP intoxication may cause *'deleterious cardiac effects and morphologic damage in the acute stage.'* Late arrhythmias may occur with the time period extended in the case of selected nerve agents. [220] While the importance of the HDL-associated enzyme paraoxonase 1 (PON1) in OP detoxification has been known for some time, [221,222] plasma PON 1 activity level is a risk factor for vascular disease. [223]

While it is not known what enzymes play a role in detoxification of TCP, the enzyme PON1 for example plays a major role in the detoxication of diazoxon and chlorpyrifos oxon. [224] PON 1 status can also have a major influence on carboxylesterase mediated detoxification of selected OP compounds (malaoxon, chlorpyrifos oxon and diazoxon). [222] The known synergistic effects between organophosphates and pyrethrins, based on carboxyesterases inhibition, can be expected in the presence of tricresylphosphates. [225]

Mitochondrial dysfunction has recently been strongly implicated in preliminary studies as the immediate cause of CFS symptoms. [226] However it was unknown whether the damage to mitochondrial function was a primary or secondary effect to one or more of a number of primary conditions. The neurobehavioural syndrome following exposure to OPs is reported to have the same clinical features as CFS. [227]

In terms of cancers in workers exposed to antirust oils, a variety of tumors were reported, for which N-Phenyl-alpha-naphthylamine (0.5%) was thought likely to be responsible. [228] While petroleum oil mists may have a carcinogenic effect on the skin and may elicit cancers in other organs and tissues, [229] there is little information about formulations containing proprietary additives, with it being difficult to generalize about human health effects to such complex mixtures. [180] Allergic contact dermatitis is reported as an effect of exposure to oil mist additives. [180]

The UK CAA published cabin air study [83] reports that TCP exposure can cause symptoms of irritation, neurotoxic, general effects and toxic encephalopathy, while PAN is listed as a suspected mutagen and carcinogen and short chain organic acids, known irritants are capable of causing lung injury. A wide range of substances were identified in the cabin air investigations including organic acids as expected breakdown products of the base stock, alkanoic acids, aldehydes and ketones, TMP/pentaerythritol base stock esters, TCP isomers, phenyl alpha naphthylamine (PAN) and dioctyl diphenylamine amongst others. Listed effects if exposure occurs in sufficient quantities, are noted to include: eye and respiratory tract irritation, dizziness, eye burns/damage, chemical burns to the respiratory tract (may be delayed), systemic effects, burning sensation, coughing, wheezing, laryngitis, shortness of breath, headache, nausea, and vomiting, and delayed pulmonary oedema amongst others. [83]

Some previous research into these matters used data not related to contaminated air exposures. Future researchers should examine reports and studies carefully to ensure conclusions are valid and not based on irrelevant data. [230]

4.3.7 Discussion: Aerotoxic Syndrome

The term Aerotoxic Syndrome was proposed in 1999 [19,29] as a discrete occupational health condition associated with exposure at altitude to atmospheric contaminants in aircraft cabins from aircraft synthetic lubricants and other fluids, temporarily juxtaposed by the development of a consistent symptomology of short and long-term effects. [9] A number of studies had previously been drawn together. [9,21]

The studies could be criticised for not following traditional epidemiological practices. However the case studies and surveys show the only available independent data describing health effects in aircrew related to exposure to cabin air as well as contaminated air events with the majority of cases directly related to smoke and fumes (predominantly oil/hydraulic fluid related) in aircraft. Health effects are not limited to aircrew and have been identified as a passenger issue as well.

Table 4-11 has been expanded to include the more recent aircrew health surveys related to cabin air quality including those undertaken as part of this thesis. [47,49]

The various studies show a consistent pattern of symptoms. The variations could be said by some to show *'multitudinous and variable',* [24] however, it would be incorrect to regard such symptoms as being entirely different from each other. [9] They point to a basic pattern of dysfunction and show the clear need for the symptoms to be re-categorised with standardised definitions using symptom clusters. [9] For example the failure crew understanding terminology such as parathesias and numbness or the difference in terminology related to for example chemical sensitivity and allergies, which has previously been highlighted. [28] The table does not include all data collated and will not include all effects experienced, as crew have identified a pattern of not considering certain symptoms relevant and are unaware of the pattern of effects that could be related. The 2009 BAe 146 findings clearly support a non self selected working population (required to meet set international medical standards) showing similar patterns of ill health.

Table 4-11 supports the need for re-categorisation of symptoms with clearer definitions, so as to enable consistent reporting of signs and symptoms in individuals. These could include:

- Loss of consciousness/ inability to function;
- Symptoms of direct irritation to the eye, airways or skin;
- Respiratory symptoms secondary to irritation;
- Skin symptoms secondary to irritation;
- Gastrointestinal symptoms;
- Neurological symptoms;
- Neuropsychological symptoms related to cognitive, memory and behavioural functions;
- Non specific general symptoms;
- Sensitivity; other

Table 4-11: Studies reporting signs and symptoms in aircrew from aircraft contaminated air.

FOLLOWS ON THE NEXT THREE PAGES

Table 4.11: Studies reporting signs and symptoms in aircrew from aircraft contaminated air

	Reference	26	194	27	19	21	28	47	49	63	192	193	59
	Year	**1983**	**1983**	**1983**	**1998**	**2001**	**2002**	**2002**	**2003**	**2005**	**2005**	**2009**	**2009**
Cluster / Symptom	**Number of cases / Symptom**	**89**	**58**	**248**	**112**	**7**	**50**	**21**	**106**	**60**	**38**	**3700**	**219**
General	Fatigue, exhaustion					7/7	62%	68%	53%	48%	84%	79%	35%
	Joint pain, muscle weakness /cramps			29%		2/7	38%	16%	15%	10%		45%	13%
	Chemical sensitivity					4/7	72%	47%	15%		42%	22%	7%
	General increase in feeling unwell							47%	39%		60%		
Nervous System - Neuropsychological	Headache, severe headache, head pressure	25%	9%	52%	26%	7/7	86%	68%	52%	58%	71%	42%	28%
	Dizziness	47%	2%	35%	6%	4/7	72%	68%	52%	37%	45%	38%	16%
	Disorientation	26%		36%	15%	4/7		26%	11%		30%		27%
	Light-headed, feeling faint or intoxicated	35%	3%	54%	32%	7/7		68%	52%				2%
	Trouble thinking or counting, word blindness, confusion, coordination problems	26%		39%		6/7	58%	47%	30%	50%	76%	44%	45%
	Memory loss, memory impairment, forgetfulness					7/7	66%	47%	18%	50%	76%	55%	28%
	Behaviour modified, depression, irritability, anxiety	26%		20%		4/7	40%				29%	64%	9%
Nervous System - Neurological	Effects on vision (blurring, loss of visual acuity)	11%		13%	1%	4/7	50%	10%	5%	8%	8%	43%	8%
	Shaking/tremors/ parathesias	9%			3%	3/7	40%				34%	12 % (31%)	12%

	Reference	26	194	27	19	21	28	47	49	63	192	193	59
	Year	**1983**	**1983**	**1983**	**1998**	**2001**	**2002**	**2002**	**2003**	**2005**	**2005**	**2009**	**2009**
Cluster / Symptom	**Number of cases / Symptom**	**89**	**58**	**248**	**112**	**7**	**50**	**21**	**106**	**60**	**38**	**3700**	**219**
	Numbness (e.g., fingers, lips, limbs)				2%	4/7		26%	16%		34%	31%	7%
	Balance problems					4/7	62%	26%	5%		32%	34%	8%
	Fainting/loss of consciousness/grey out	4%		4%		3/7	14%					4%	4%
Nervous system-Senses - Other	Hot flashes (Body temp)												
	Altered smell/taste						15%					19%	
Local effects - Irritation	Irritation of eyes, nose and throat	35%	48%			7/7		84%	59%	48%	80%		25%
	Eye irritation, eye pain		45%	74%	24%	4/7	76%				73%	57%	
Local effects – Skin	Itch, Rashes, blisters (on uncovered body parts)					4/7	48%	21%	20%	17%	5%		11%
Local effects – Respiratory	Difficulty in breathing, chest tightness, respiratory problems		5%	68%		3/7	62%	37%	7%	28%	57%	24%	16%
	Respiratory distress, shortness of breath, respiration requiring oxygen			73%	2%	4/7	62%	37%	7%			34%	
	Repeated chest Infections												4%
	Severe pulmonary effects												1%
	Cough		3%	69%		2/7	12%					52%	5%
	Throat irritation, burning throat, gagging and coughing	2%	5%	64%	43%	2/7	76%			28%	79%	45%	

	Reference	26	194	27	19	21	28	47	49	63	192	193	59
	Year	1983	1983	1983	1998	2001	2002	2002	2003	2005	2005	2009	2009
Cluster / Symptom	Number of cases / Symptom	89	58	248	112	7	50	21	106	60	38	3700	219
	Sinus congestion	35%	24%	54%	5%	2/7						73%	
	Nose bleed			17%		1/7	4%				13%	28%	
	Loss of voice			35%		1/7						34%	
Systemic Toxicity Cardiovascular	Chest pains	7%		81%	6%	2/7	22%					15%	1%
	Altered heart rate or palpitations										24%	32%	12%
Systemic Toxicity – Gastrointestinal	Nausea, vomiting, gastrointestinal symptoms	26%		23%	8%	6/7	58%	10%	21%	35%	84%	33%	14%
	Abdominal spasms/cramps/ diarrhoea	26%				3/7	20%	10%	29%		21%	37%	4%
Systemic Toxicity – Renal	Change in urine / Polyuria- frequency of urination			3%			4%				3%		1%
Systemic Toxicity – Endocrine	Hypothyroidy												
Systemic Toxicity – immunological	Immune system effects						30%	21%	5%		3%		1%
	Increased incidence of flu/cold												7%
	Altered thyroid function												
	allergies						25%						
Cancer	Cancer								1%				3%

The Australian Senate Inquiry found that contaminated air in aircraft was responsible for short and medium term health effects in aircrew (medium term was identified as up to 10 years [231]). [34] A consensus statement by a group of leading international experts attending the BALPA 2005 conference on contaminated air found that: [125]

- *'There is a workplace problem resulting in chronic and acute illness amongst flight crew (both pilots and cabin crew);*
- *The workplace in which these illnesses are being induced is the aircraft cabin environment. This is the resulting in significant flight safety issues, in addition to unacceptable flight crew personnel health implications;*
- *Further, we are concerned the passengers may also be suffering from similar symptoms to those exhibited by flight crew.'*

However, the response from the aviation industry and many in the medical profession in general has been quick to insist there is no connection between chemical exposures in flight and ill effects. In addition to the general denial of liability, many in the industry seek to utilise a dose response effect on one body system, despite the fact that no monitoring has been done during exposure events (except 1 documented case on a B757 with a *'minor fume event'*) and hence there is virtually no recording of the health effects during such official studies. The UK COT committee inappropriately found that there was not sufficient data on chemicals that may be found during a contaminated air event and therefore could not make a causal association between such incidents and ill health. However it suggested an association was plausible between exposures and acute adverse effects. [6] Additionally there is a lack of will by the medical profession to accept that such exposures require specific protocols to identify adverse effects both short and long-term. The varying responses and inappropriate actions are clearly stated as follows:

- *'The response of the medical profession is highly variable. At one end of the spectrum, there is rejection of the existence of a toxic cause, including a tendency to minimise the severity of symptoms and a tendency towards inaction on the grounds of insufficient evidence. In the middle of the spectrum, there is an admission of ignorance (however, in* *a number of cases, treatment has gone as far as surgical intervention). Towards the other end of the spectrum, there is acknowledgment of the presence of disabling symptoms and illnesses but this remains couched in the realisation that further enquiry and research are needed.' [63]*

- *'The COT has deferred to Science for arbitration over the nature and importance of the problem. In doing so there is under utilization of available information on the cabin air problem and over emphasis on scientific uncertainty. Historically this approach to public health problems has delayed implementation of preventive measures at a high cost to public health.' [232,233]*

However, a 2008 FAA funded medical protocol, [198] which provides clear support for medical practitioners has not been widely publicised even by the FAA who funded it.

A recent review of the use of the term Aerotoxic Syndrome found that as the term has not yet been officially recognized, guidelines for diagnostic procedures have not been established. [234] The report concludes that until Aerotoxic syndrome is officially recognized with guidelines for diagnostic procedures established. *'patients requiring specific investigations may not be appropriately referred, or tests may be performed unnecessarily.'*

In addition to the identifiable industry data acknowledging contaminated air events are occurring, it is necessary to look at causality as it is recognised that epidemiological studies can be problematic in trying to show a cause and effect. [235] The 1965 published Bradford Hill Criteria provides a strong method of applying epidemiological data to causation. [236,237]

The criteria established by Bradford Hill shown in Table 4-12 helps to address whether the condition/illness is environmental or occupational. [63]

Table 4-12: Bradford Hill criteria

Bradford Hill	Application	Y/N
Strength	There is an extensive history of aircrew reporting exposures to contaminated air in aircraft with adverse effects. This is acknowledged to occur by a growing body within the aviation industry including the regulators failing pilot medicals [238] based on their doctors connection to contaminated air. ***** [2,6,8,26,34,37,38,39,50,77,82,83,95,98,99,100,101,105, 109,117,125,127,133,191,198….]	✓
Consistency	Effects repeatedly observed by different people in differing places, circumstances and times.	✓
Specificity	Onset of symptoms in crew is specific to those flying.	✓
Temporality	Close relationship between the time of exposure to fumes or smells in the aircraft and the time of onset of the symptoms.	✓
Dose Response	While some exposures are intense and associated with adverse effects, many report symptoms at lower exposures and there is a wide variation in response to exposure events (likely due individual susceptibility). The likely effects of many environmental toxins are not well known, particularly at low exposures and especially at or below conventional toxicological effect levels.	✗
Plausibility	The occurrence of symptoms is plausible - both biologically and in terms of engineering. OP additives to engine oil are known to be neurotoxic and the use of bleed air to supply the air conditioning system in the cabin explains how cabin air is contaminated.	✓

Coherence	A cause and effect interpretation of the association between illness and flying has coherence with the biology and natural history of a neurotoxic disorder.	✓
Experiment	Each crew member - describing symptom onset following exposure, with subsequent recovery and recurrence - provides own experimental evidence. This is a valid form of trial in which one individual repeatedly serves as both study subject and their own control.[†]	✓
Analogy	With regard to the development of a non-specific illness following exposure to synthetic chemicals at work, the cabin air experience of aircrew is analogous to a number of other occupational groups (notably, Australian F-111 maintenance workers, Vietnam veterans, Gulf war veterans and agricultural workers).	✓

This reasoning suggests a causative relationship in crews being exposed to contaminated air. [63] However, there is a pattern developing involving crew who were exposed to the contaminated air over a long period, were not at the time particularly aware of acute effects and saw any as normal and frequent and have then developed the same pattern of long-term effects. Additionally, a range of other effects are possibly supportive of an association between exposures and health.

Alternatively, other explanations for the problems being seen that are not work related chemical exposures could be raised. Possible reasons could be a psychological disorder, malingering or alternative medical diagnosis. However the evidence is not supportive of this and such theories have been dismissed on many occasions along with recognition of cases of misdiagnosis and failure to diagnose. [63,160,172,173,190,191,232,233] The pilots in this study are not

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* Note added by author

† There is a need to further develop research in humans (note added by author)

having their medicals failed by the regulator based on malingering or a psychological disorder.

Despite all the evidence and the approach taken by Bradford Hill, many remain resistant to accepting contaminated cabin air is a significant problem due to the health effects that it causes. [63] Hill sounded a warning regarding new health problems stating that an observed association *'may be new to science or medicine and must not therefore be too readily dismissed as implausible or even impossible'.* [63,237] It should be remembered that:

- *'As seen in the history of medicine, new illness precedes research, and scientific understanding of disease lags behind the occurrence. A willingness by the medical profession to take public health action well in advance of full scientific understanding of the causative mechanisms of this problem is required... Our history of medicine is too easily forgotten: In 1854, John Snow cut short a cholera epidemic by the forthright, practical action of removing the handle from the Broad Street water pump. [239] This was 29 years before the discovery of the cholera bacterium. He used the available information to take responsible action.'* [63]

The aviation industry and particularly the aviation medicine community have been resistant to accepting that contaminated air in aircraft can cause ill health and specifically denies the use of the term Aerotoxic Syndrome. [24,240] The former British Airways Chief Medical Officer and Airbus Aeromedical advisor suggested that the symptoms raised in Aerotoxic Syndrome are too broad and inconsistent, based on too small a population and are consistent with symptoms seen in 70% of the population on any given day and are similar with symptoms of chronic hyperventilation. [240] The symptoms seen are not upon review, generally consistent with the initial onset of hyperventilation and are not the same as those reported in pilots suspected of hyperventilation. [241] Additionally, oxygen has been reported as beneficial in cases where crews have developed adverse symptoms in the cabin air environment discussed here and is a recommended operating practice. While there my be some overlap in a few selected symptoms, the contaminated cabin air issue is well documented, accepted as a design feature of using bleed air and often recorded as an aircraft technical defect/incident. Additionally, the oil manufacturers and the oil MSDSs and chemical databases and many within the airline industry recognize that many of the symptoms reported occur on inhalation of the oils or heated oils or substances in the oils or decomposition products. Additionally, the pilot group is not a cohort particularly subject to stress and anxiety, given the high level of training. Hyperventilation has not been suggested in any industry investigations and according to the author has only been suggested by 2 doctors. Both doctors are considered to show significant conflict of interest with one as a former airline CMO and current Airbus medical technical advisor [240] and the other doctor's intentions and credibility have been seriously questioned, despite being a panel member that accepted short term effects were linked to contaminated air and system defects. [37,43,44,45,46,242,243] Others have suggested that the symptoms related to air quality are most likely related to other factors including decreased pressure, crowding, inactivity, motion, fear, vibration, fatigue, noise and the cabin environment. [1,2,3,4,244]

The need for further epidemiological or medical research has been dismissed as unnecessary until cabin air quality studies have determined what the particular chemical substances might be and in what quantities and dismissed the need for a medical protocol based on the same reasoning. [6,55,245,246] This is still the position, despite the US FAA having published an extensive medical protocol in 2008 based on the evidence currently available. [193] The Aerospace Medical Association following statement may go part of the way to explaining how the airline industry looks at this issue.

- *'If significant exposures to toxic substances in the aircraft cabin can be demonstrated and epidemiologically linked to crew/passenger illness this would give credence to the argument that aircraft cabin air is... unhealthful and causes adverse health effects.'* [2]

However, to date, the airline industry and Government studies into cabin air quality while not being undertaken during fume events, have failed to take into account a number of considerations including: hypoxic environment; reduced cabin pressure, humidity; synergistic effects; inapplicability of exposure standards for the aircraft environment, suitable monitoring, the inadequacy of dose/response in some cases, inhalation to heated mixture of substances amongst others. Therefore, until aircraft air monitoring studies are adequately undertaken and interpreted, the use of such data is unlikely to lead to a further understanding of the health and flight safety effects. At present, there is still little will being seen by the aviation industry to undertake appropriate studies. As an example, the CAA despite clearly recognizing the problem in at least 2002, then stated the position publicly in 2004, that no health research or protocols could be initiated until the air monitoring as shown above had been completed. [50,55] As of mid 2010 the UK Government has not published it's completed contaminated air monitoring studies, which were commenced in 2007 after the House of Lords said such studies should be urgently undertaken. [247,248]

Many have suggested the symptoms are too wide and vague and that the term syndrome is inapplicable. [24,240] However, the manifestations of organophosphate poisoning affect many body systems as can be seen in Figure 4-17: Manifestations of OP poisoning. [185] However, selected syndromes are said to give rise to constellations of similar symptoms and affect all major systems and organs of the body. [249]

The recent US Gulf war studies found that research clearly demonstrated that an *'illness from a complex of multiple symptoms'* resulted from occupational service. [188] The specific symptoms affecting individuals can differ from person to person, but the general types of symptoms were *'remarkably consistent'* across diverse populations. The report considered the question of whether the symptom complex related to one syndrome with several subtypes or several syndromes, could only be resolved with more objective markers.

The report considered that the term Gulf War Illness as a consistent complex set of symptoms affecting a defined population, fits most definitions of what is considered a syndrome. Finally, it was considered that the syndrome may not be unique with more than one type of pathophysiological process leading to similar overlapping profiles. The central issue was that a unique population were identified with a pattern of identifiable persistent symptoms as a consequence of their occupation, rather than whether this was a syndrome or multiple syndromes, unique or otherwise. There was overwhelming evidence demonstrating Gulf War Illness, however labelled, is a widespread problem, with no evidence to the contrary. [188]

Figure 4-17: Manifestations of OP poisoning

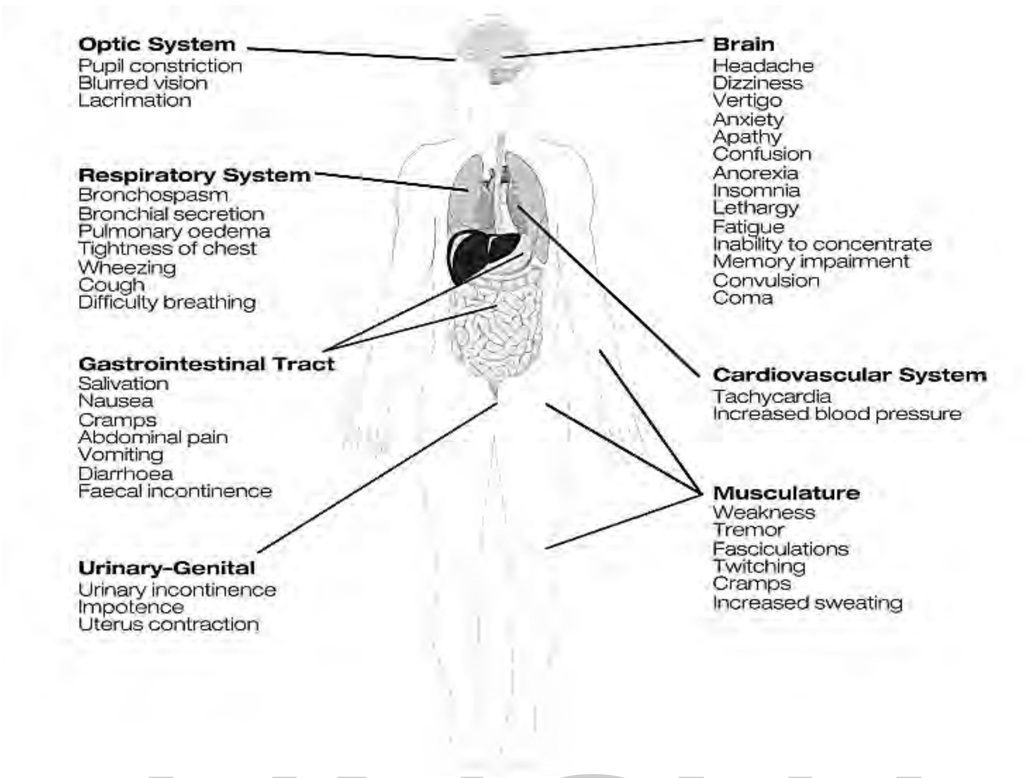

Image courtesy of The Journal of Occupational Health and Safety, Australia/New Zealand, CCH Australia Ltd.

The UK Government Lloyd Inquiry into the Gulf War found the use of the term syndrome acceptable. [250] While they suggested the symptoms were not unique, the extent and intensity of the symptoms was unusual and supported the terminology syndrome despite possible multiple causes (in the Gulf occupational setting) and no one single pathology.

The differences in the various studies undertaken in Table 4-11 related to aircraft contaminated air environments and general flight support a pattern of symptoms related to local effects from exposure to an irritant, overlaid by development of systemic symptoms in a number of body systems including: nervous system, respiratory system, gastrointestinal, cardiovascular and possibly immune system. The symptoms may be related to these particular body systems or may be listed more generally as chronic fatigue, chemical sensitivity or weakness.

The symptoms in Table 4-13 are sufficiently consistent to indicate the development of a discrete occupational health condition. The term aerotoxic syndrome is therefore a suitable means to describe this condition.

Table 4-13: Aerotoxic Syndrome: short- and long- term symptoms

Short-term exposure	Long-term/residual exposure
Irritation	
• irritation of eyes, nose upper airways, skin	• irritation of eyes, nose upper airways, skin
Sensitivity	
	• signs of immunosupression • chemical sensitivity leading to acquired or multiple chemical sensitivity
Gastro-intestinal symptoms	
• nausea • vomiting	• nausea • vomiting • diarrhoea • abdominal pain and spasms
Skin	
• rashes • blisters on exposed skin • hair loss	• skin itching and rashes • skin blisters (on uncovered body parts) • hair loss
Neurological symptoms	
• blurred or tunnel vision • nystagmus • shaking and tremors • parathesias • loss of balance and vertigo • seizures • loss of consciousness	• numbness (e.g. fingers, lips, limbs) • parathesias • tremors • balance problems
neuropsychological symptoms	
• memory impairment, headache • light-headedness • dizziness • confusion • disorientation • feeling intoxicated performance decrement	• memory impairment • cognitive problems, such as performance decrement, trouble thinking, lack of co-ordination • severe headaches • head pressure • dizziness • sleep disorders • depression • anxiety
Respiratory symptoms	
• cough • breathing difficulties (e.g shortness of breath) • tightness in chest • respiratory failure requiring oxygen	• breathing difficulties (e.g. shortness of breath), tightness in chest • respiratory failure • susceptibility to upper respiratory tract infections
Cardiovascular symptoms	
• changes in heart rate • palpitations	• chest pain • changes in heart rate • palpitations
General	

Short-term exposure	Long-term/residual exposure
• fatigue exhaustion	• weakness and fatigue (leading to chronic fatigue) • exhaustion • hot flashes • joint pain • muscle weakness and pain.
Other	
• Various other reported symptoms	• Various other reported symptoms

Features of this syndrome are that it is associated with aircrew exposure at altitude to atmospheric contaminants from engine oil or other aircraft fluids, temporarily juxtaposed by the development of a consistent symptomology including short-term irritant, gastro-intestinal, respiratory/cardiovascular and nervous system effects, and long-term central nervous, respiratory/cardiovascular, general and immunological effects. [9] Further identifiable chronic problems may be occurring.

This syndrome may be reversible following brief exposures, but features are emerging of a chronic syndrome following significant exposures.

The presence of contaminants in flight decks and passenger cabins of commercial jet aircraft should be considered an air safety, occupational health and passenger health problem. [9]

4.3.8 Conclusions

The conclusions that can be drawn from these surveys and studies are that aircrew are facing a real problem with identified and acknowledged workplace exposure to a mixture of heated contaminants at altitude. In addition to adverse implications to flight safety, short term effects as well as a pattern of emerging long-term effects are occurring.

The problems identified can be chronic and disabling and are frequently misdiagnosed or under-diagnosed. The problem is continuing and there is evidence that passengers can and are exposed as they breathe the same air.

Aviation industry documentation shows that engine oils and hydraulic fluids contain toxic and hazardous ingredients, which cause irritation, sensitisation and neurotoxicity. If such ingredients leak into the air, toxic exposures are possible. Such exposures are generally ignored by the aviation industry, however, where irritation, discomfort or toxicity occurs adversely affecting the health and performance of crew, or the health of passengers, this must be considered a flight safety risk and health issue and given appropriate priority.

Where oils leak out of the engines and contaminate the cabin air, this may cause crew or passengers to suffer discomfort, irritation, toxic, immunotoxic and other consequences of exposure. This is a direct contravention of a number of regulations including the principal ventilation airworthiness regulations (FAR/CS 25.831).

Contaminated air from engine or APU leak events involving engine oils and other aircraft contaminants into the passenger cabin occur frequently. Such leaks, widely identified in industry documentation are under-reported, generally seen as normal and dismissed as a nuisance. Appropriate reporting, follow up investigations and health investigations for those exposed including passengers are warranted.

Where contaminants impair the performance or affect the ability of pilots to fly planes, as has been reported for a number of incidents, this is a major safety problem; yet pilots and cabin crew continue to fly when experiencing discomfort.

There is a lack of understanding amongst crew about the toxicity of the oils and substances, the necessity to use oxygen and the occupational health and safety implications. This problem is further compounded by airline industry personnel who also have a lack of understanding of the toxicity and OH&S implications, but often demonstrate a clear conflict of interest favouring corporate objectives.

Attempts by the industry to minimise this issue, such as acceptance of under-reporting of incidents; inadequate recognition of the extent of the problem; inadequate adherence/interpretation of the regulations; inadequate monitoring; inappropriate use of exposure standards and care provided to crew reporting problems, have perpetuated this problem.

The health implications, both short and long-term, following exposure to contaminants being reported by crew and passengers must be properly addressed. A syndrome of symptoms is emerging, called Aerotoxic Syndrome, suggesting these exposures are common and a substantial group of affected individuals exists. Further identifiable chronic problems may be occurring and need to be investigated.

Contaminants in the air of an occupational environment should, under normal circumstances, alert management to a potential problem. [210] Proper medical and scientific research needs to be undertaken in order to help airline management and crew to better understand both the short-term and long-term medical effects of being subjected to air contamination.

Over the past fifty years, the concept of duty of care has emerged as one of the most important legal responsibilities for employers. In the workplace, the duty of care of an employer to its workers has been crystallised into OHS legislation. Aviation safety is something that a person outside the industry would understand to cover all aspects of safety, including the health and safety of its workers. However, this does not seem to be how all aviation industry insiders see it. Many in the industry see aviation safety as being about making sure the planes keep flying and measure safety based on the number of hull losses related to technical problems. [99] Effectively, both the aviation regulators and the airlines themselves think that OHS is not their business – which is strange, because if they do not look after the health and safety of workers in the industry, then who will?

More scientific and medical research and case controlled studies are needed into the short and long-term effects of exposure to contaminated air. Until this is completed, many in the aviation industry will seek to deny and downplay the issue of contaminated air exposures to protect their entrenched positions of denial.

The fact that there was extensive awareness and concern about the hazards of the toxicity of inhalation of engine oils extending back to the 1950s and 1960s makes this position of denial or minimization all the more inappropriate.

Veterans of the 1991 Persian Gulf War reported a range of medically unexplained symptoms after the conflict, which became known as Gulf War syndrome or illness (GWS/GWI). [188,250,251,252] Symptoms attributed to this syndrome had been wide-ranging and included acute and chronic ailments. These have typically included persistent memory and concentration problems, chronic headaches, widespread pain, gastrointestinal problems, and other chronic abnormalities not explained by well-established diagnoses.

Gulf War Veterans who complained initially, like their aviation counterparts who complain of Aerotoxic Syndrome effects, received little support, with many claiming the syndrome did not exist. In fact as with Aerotoxic Syndrome, many attempted to deny the problem or blame it on some other cause, all in an effort to prevent or delay a proper investigation into the syndrome. [253,254,255,256] It took many years of lobbying until funding was provided to enable proper research to be carried out by many leading researchers, including Professor Robert Hayley. [204,257,258,259,260,261,262,263,264, 265,266,267]

In the USA in 2008, the federally mandated Research Advisory Committee on Gulf War Veterans' Illnesses released a 452-page report indicating that roughly 1 in 4 of the 697,000 veterans who served in the first Gulf War are afflicted with the disorder. The report stated that *'scientific evidence leaves no question that Gulf War illness is a real condition with real causes and serious consequences for affected veterans.'* [188]

The same effort now needs to be applied to those suffering from Aerotoxic Syndrome. As Professor Hayley stated in 2007, the science and technology to do the research into Aerotoxic Syndrome exists, *'all that is lacking is the political will to do so'.* [85]

The significant paralysis caused by TCP isomers during the American prohibition over 80 years ago, raises the question whether it is desirable to inhale these molecules during an oil leak event.

4.3.9 References

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5 What is in Contaminated Air?

5.1 Introduction

A variety of air monitoring studies have been carried out in an attempt to assess the problems of contaminants in aircraft at altitude. These studies are frequently cited suggesting air quality in aircraft is of an acceptable standard and cannot be the cause of aircrew or passenger adverse health effects. Much of this literature cannot be used to evaluate problems of contaminated bleed air.

A review of some of the publicly available air monitoring studies will be examined looking at the methodology, timing and objectives of air monitoring, the findings and any associated health studies undertaken.

An analysis of various monitoring studies has been previously undertaken by the author. [1]

It is suggested that as no exposure data are available to identify contaminants in cabin air during air quality incidents and there is no standardised approach to collect human data during such incidents, a causal link between cabin air and health is problematic. [2] According to the Aerospace Medical association, *'unhealthful'* cabin air causing adverse effects may exist if *'significant exposures to toxic substances in the aircraft cabin can be demonstrated and epidemiologically linked to crew/passenger illness.'*[3] While acute effects from exposure to contaminated cabin air were deemed plausible, a causal link was dismissed although *'the need to obtain objective measures of exposure in epidemiological studies'* was acknowledged. [4]

Chemical exposures in aircraft in flight have been reported. In 1953, The US Aeromedical Association first expressed their concerns about the toxicity risks of cabin air contamination by hydraulics and lubricants. [5] Other toxicity risks have been identified more recently, either as part of the chemicals routinely used in operating airplanes, [3,6,7,8] or as toxicological factors in aviation accidents. [9]

Sources of contamination are recognized to include: hydraulic fluids, engine oils, deicing fluids, fuel, exhaust fumes, ozone, pesticides, solvents, anti-corrosion spray, paints and electrical odours amongst others. [10,11,12,13] While the intake of chemicals from lubricating oils, hydraulic and deicing fluids and their degradation products are recognized to enter the bleed air supply, [2] the toxicity of substances used in jet engine oils and hydraulic fluids is well recognized. [14,15,16,1718,19] Other environmental factors such as jet emissions, chemical carcinogens, fuel, [20] along with air quality, [21] hydrocarbon pollutants, cabin air pollutants, hydraulic fluids and others, are associated with the flying environment. [22]

Significant contaminants include: aldehydes; aromatic hydrocarbons; aliphatic hydrocarbons; chlorinated, fluorinated, methylated, phosphate or nitrogen compounds; esters and oxides. [12,15]

Jet engine oils have an appreciable hazard due to toxic ingredients but are safe in use provided appropriate safety precautions are followed and the oil stays in the engine. [15] However, the oils and other contaminants can find their way into the air supply where passengers and crews are located, through incidents such as engine or APU oil leaks, seal failures and fluid ingestion by the engines or APU.

One additional important consideration is the lower partial pressure of oxygen that is present in the cabins of planes flying at altitude. [23]

5.2 Aviation oil leaks

The oils and hydraulics used in aircraft engines can be toxic, and specific ingredients of oils can be irritating, sensitising (such as N-Phenyl-alpha-naphthylamine) or neurotoxic (for example, ortho-containing triaryl phosphates such as tri-orthocresyl phosphate, di or mono-orthocresyl phosphate). [14,15] If oil or hydraulic fluid leaks occur, this contamination may be in the form of unchanged material, degraded material from long use, combusted or pyrolised materials. These materials can contaminate aircraft cabin air in the form of gases, vapours, mists and aerosols. [12,13,15]

Some of these contamination problems can persist for decades. For example, a problem of oil contamination of the air conditioning system of the BAe 146 was first noted by the aircraft manufacturer in 1984, [24,25,26] and was the subject of a specific term of reference for an Australian Senate Aviation Inquiry held from 1999 to 2000, over fifteen years later. [27]

While changes in product formulations have attempted to make less toxic products, [14] concern still exists as to the potential toxicity that exposure to these materials may cause. [28]

Contaminated air events are under-reported and are not rare. [29,30] There is a spectrum of defects and malfunctions in an airplane engine ranging from the trivial to the serious, to the catastrophic. [29] As trivial malfunctions can escalate into serious events, it is necessary to ensure that all types of malfunctions are identified, investigated and rectified. [29] Leak incidents are much more frequent than those documented, correlated to the less obvious aircraft fluid leaks and residual contamination that are seen by many as a normal part of flying. [29]

For the purposes of discussion below, events leading to leak, smoke or fume incidents will be combined as *'contaminated air'* or *'fume events'*. Because of the ways in which the conclusions of individual reports are interpreted and then used by various sectors of this industry, it is necessary in this thesis to provide quotes from the individual reports. This will ensure a better understanding of the statements and conclusions that were actually being made in these reports.

The aviation industry itself acknowledges that air quality exposure events are primarily due to oil leaking into the air supply. [29,30]

In 1952 it was recognized that turboprop and turbojet engines with higher compression ratios, and more power had forced temperatures of oils and bearings up, with better oil compatibility with seals required, if seal leakage was to be minimized. [31]

In 1955, the bearing and lubricant problems in aircraft turbine engines were reported as *'quite severe'* due to the occurrence of high temperatures and rotative speeds. [32] Non-toxicity was listed as one of the six lubricant general requirements. A further 1956 report notes that *'a positive air pressure gradient is generally provided to assist in sealing oil in most main shaft applications. This is achieved by pressurizing a cavity between two seals'* with the air pressure being responsive to variations in engine operating conditions. [33] The need for a positive air pressure gradient or the need to ensure that air pressure external to the bearing chambers exceeds the local air pressure, to prevent engine oil escaping and contaminating the compressor air flow was recognized as recently as 2009. [34] The 1956 report also states that zero oil leakage which is chiefly necessary due to the *'common practice of using compressor bleed air to pressurize or refrigerate aircraft cabins'*, is difficult to obtain under all operating conditions, with any oil leakage into the compressor air flow able to *'cause serious cockpit contamination problems due to the formation of toxic fumes.'* [33] The Grade 1 oil MIL-L-7808 was noted to decompose at temperatures above 400°F (204°F) with *'the formation of various vapors.'*[33]

In 1962, an internal industry document reports that: [35]

- *'the utilization of engine compressor bleed air for cabin pressurization and air conditioning exposes the crew to air which could possibly be contaminated with decomposition products of MIL-L-7808 lubricant… a small leak in the front compressor section of the engine may allow the lubricant to escape from the engine and pass into the compressor bleed air section where under high compression and temperature the oil breaks down chemically forming toxic compounds, thus contaminating the bleed air going into the cabin… The extent of the contamination would be governed by the small amount of lubricant sealed in the bearings. The* *engine is the main source of bleed air contamination and the extent of the contamination is governed by the oil leakage rate of the front compressor seals… it cannot be overemphasized that oil lost in the compressor section of the engine contributes to bleed air contamination.'*

Labyrinth seals, the most extensively used seal in the aerospace industry, were said to be: [36]

- *'reasonably effective when properly designed with a sufficient number of teeth, of sufficient length, and when operated with a small clearance. It loses performance fast when wear occurs due to shaft vibration or when thermal or transient conditions dictate a larger clearance installation.'*

A 1966 Douglas Aircraft Corporation report stated that: [37]

- *'In many cases contamination problems were encountered. The major contaminants were traceable to lubricating oil leaking into the engine compressor through the bearing seals… although the oil itself was not especially objectionable, the high temperatures encountered within the engine compressor caused the oil vapour to decompose into extremely noxious and irritating substances. (Ref 1) Several unexplained fatal crashes involving single pack carrier based turbine powered aircraft with direct bleed air conditioning systems installed were attributed (rightly or wrongly) to contaminated engine bleed air.'*

Reference 1 refers to a 1966 FAA report. [38] Aircraft in the conceptual design stage (1960's) using: [37]

- *'advanced technology engines with much higher compression ratios resulting in bleed air extraction temperatures, even for the lower bleed stages, well above the critical decomposition temperature of conventional engine lubricating oils. (ref 4) These higher bleed temperatures will prevail during most normal operating conditions and not for short-terms, hot day, operation as is the case for current jet-powered aircraft.'*

Work of the UK COT [4] refers (in an unreferenced capacity) to 1954 work undertaken on behalf of the USAF suggesting the critical temperatures were in the range of 600-700°F (316-371°C). [39,40]

Another McDonnell Douglas report in 1970 advised that: [41]

- *'Contamination of engine bleed air by engine oil, once a serious problem, has been almost eliminated, by the efforts of engine manufacturers. Nevertheless, the possible consequences of a severe oil leak are sufficiently serious to make additional knowledge on the subject desirable. Current Douglas design practice is to guard against the possibility of toxic products of oil decomposition occurring in the air conditioning system by taking only low temperature bleed air.'*

A Rolls-Royce report in 1969 recognized that evaporation loss of oil: [42]

- *'constitutes only a minor part of the oil consumption in Rolls-Royce gas turbines, the major part of the consumption representing loss of liquid oil arising from permissible leakage past certain seals, escape of mist or aerosol through breathers and losses incurred during filter inspections in service. These are made good by "topping up" the system with fresh oil.'*

In a 1974 Handbook published by the Garrett Corporation (a manufacturer of aircraft engines and auxiliary power units) noted that the least favourable location of an exhaust inlet: [43]

- *'is an inlet located well aft at the bottom surface of the fuselage. Fluids likely to be ingested with this type of inlet include those that may be spilled within the aircraft fuselage, fuel-tank leakage and vent-system discharge, leakage from the hydraulic system etc'.*

Exhaust inlets are often located in such a position.

In 1981, the Society of Automotive Engineers (SAE) noted in an Aerospace Information Report that: [44]

- *'Engine compressor bearings upstream of the bleed ports are the most likely sources of lube oil entry in the engine air system and thence into the bleed system contaminating the cabin/cockpit air conditioning systems.'*

A 1981 report by Royal Dutch Shell states that *'some commercially available lubricants are being stressed to the limits of the fluids capabilities.'* [45] The emphasis on reducing specific fuel consumption is accomplished partly by raising engine operating temperatures resulting in higher heat loads on the lubricant, thereby necessitating oils with greater thermal and oxidative stability.

In 1983, Mobil Oil (manufacturer of a number of aviation jet oils) noted in correspondence to a customer that: [46]

- *'if cabin air becomes contaminated with any lubricant and/or its decomposition products, in sufficient quantities, some degree of discomfort due to eye, nose and throat irritation could be experienced. Problems like these can be generally traced to improper design, improper maintenance or malfunctioning of the aircraft.'*

In 1984, British Aerospace (an aircraft manufacturer) issued the BAe 146 Service Information Leaflet *'Oil Contamination of Air Conditioning System'* that acknowledged that oil contamination of the ducting was a problem, and suggested ways in which such problems might be resolved. [24] Among other things, this leaflet recommended the development of an operational procedure called an *'Air Conditioning Pack Burnout Procedure'*. The procedure called for the operating of the system, before the first revenue flight of the day, in hot mode for five minutes (manually controlling the duct temperature at 70°C). This was said to help purge residual oil from the packs and ducting. This leaflet was replaced by another outlining a totally different engineering based process in (revision 4) 1995. [47]

In 1991 Allied Signal (maker of engines and APUs), well known in the field of bleed air, advised: [48]

- *'Several BAe 146 aircraft are having reports of objectionable odours described as 'dirty socks' or musty smells. Very little work has been done in the aviation industry to pinpoint the chemical compounds causing such odours... the odour appears to be coming from breakdown products of the oil, either through incomplete combustion on the catalytic converter, or by chemical or biological reaction occurring in the environmental control system of the aircraft.'*

In 1989, the Garrett APU Division of Allied Signal issued a Service Bulletin regarding the compressor seal assembly, noting that: [49]

- *'the current compressor seal has shown an unacceptable rate of failure which can result in smoke in the cabin' and 'the failure of the compressor seal assembly allows gearbox oil to leak into the compressor inlet resulting in smoke in the cabin. The new seal has been redesigned to improve sealing characteristics and reliability.'*

However, Service Bulletins are not mandatory. Garrett/Allied Signal recommended that aircraft operators make replacements at their convenience. [49] In fact, for one aircraft type alone, the BAe 146, there are over 200 sources of data relating to contaminated air including service bulletins, service information leaflets, all operator messages, engineering data and airworthiness directives. [26]

While all parties acknowledge that a problem exists, [29] and has existed for a long time, [50] most sectors of the aviation industry then paradoxically deny that leaks are a serious matter, suggesting that it is not an air safety issue, rather an OHS, general health or comfort issue. [29,51] This was further confirmed in a December 2004 internal CASA letter, which states: [52]

- *'CASA does not have any regulatory responsibility in relation to occupational health and safety of aircrew and to the extent that the Commonwealth civil aviation law regulates such matters as certification of aircraft (including oxygen systems), medical standards for flight crew, and flight and duty times, that law is directed to the safety of air navigation, not to the personal health and welfare of aircraft crew.'*

This view is no different to that expressed internationally.

The acceptance that the predominant source of the fumes was related to oil lubricant leakage was openly acknowledged. For example, Ansett Australia advised that:

- *'The source of the odours has been identified as primarily Mobil Jet Oil II leaking past oil seals in the engines and or APU unit into the air conditioning system'* [53] and
- *'The short-term symptoms associated with odours that have been reported on the BAe 146 and other types are substantiated. These*

odours have been generally linked with inadequate ventilation together with aircraft system defects.' [54]

In evidence to the Australian Senate Inquiry in 1999, British Aerospace stated that:

- *'Reports of cabin air odours have been received from time to time and have predominantly been determined to be due to minor systems failures such as leaks from oil seals on the aircraft engines or APU.'* [55]
- *'Every engine leaks oil from its seals and bearings.'* [56]
- *'The air supply is protected from contamination by seals, which achieve maximum efficiency during steady state operation. However, they may be less efficient during transients (engine acceleration or deceleration) or whilst engine is still achieving an optimum operating temperature. Improvements in seal design continue to increase efficiency, and when available, modifications are provided for the engines and A*PU.' [57,58]

Rolls Royce (engine manufacturer) stated:

- *'The approach adopted some years ago by Rolls Royce was to recognize the fact that in the majority of instances where cabin air contamination was a problem, it was mostly associated with small leakages of synthetic lubricant from bearing seals etc.'* [59]

In 2000, the Civil Aviation Safety Authority (CASA) of Australia advised that *'all aircraft suffer fumes as a feature of the design of air conditioning systems in aircraft.'* [51] This is supported by a 2005 SAE Air Information Report recognizing that air supply contaminants can be controlled by design when stating: [60]

- *'Improved seal design. First-generation jetliner engine bleed air was contaminated with lubricating oil to the degree that turbo-compressors were necessary to provide the cabin air. Turbine lubrication seals have been improved such that concentrations of lubricating oil in bleed air is negligible.'*

However the following SAE statement very clearly spells out how oil seal leakage is a function of the way oil seals operate and is an expected occurrence. [60]

- *'It is possible in some designs that lubricating oil may leak at greater rates when an engine or APU is started and seals not yet at operational pressure and temperature or during transient operations such as acceleration/deceleration. Some systems rely on internal air pressure to maintain the sealing interface. When an engine shuts down this interface is opened, possibly allowing some oil to exit the oil wetted side of the seal. Upon engine startup, this oil is entrained into the air entering the compressor of the engine. The seal interface is again established when the engine internal air pressure returns to operating norms.'*

Regulatory agencies indicate that *'serious impairment'* includes the loss of crew's ability to see flight deck instrumentation or perform expected flight duties. However, they also suggest this excludes purely psychological aspects of the concern of odours, and concerns about long-term exposure. [61] The UK Civil Aviation Authority (UK CAA) advised that crew discomfort such as headaches, nausea and irritation due to contamination is not their responsibility unless the safety of flight and landing are affected. [62,63]

Fume events are well recognized as often being dismissed as a nuisance only [29,30,50] and therefore not reported. When a leak occurs, it may be dismissed by the pilot as being a nuisance, in that it appears to have no apparent effect or is considered a normal part of flying or it may be considered minor and reported verbally only. [30] The failure to report defects of any kind as required can be evidenced by an incident when the head of CASA recorded an aircraft defect on a piece of paper for the next pilot instead of entering the defect as required in the aircraft maintenance log, with the defect therefore remaining unrecorded. [64,65] With regard to fumes there is inappropriate subjective interpretation of the terms *'undue discomfort'* and *'harmful or hazardous levels of gases or vapours'* specified in aviation regulations, and interpretation of this often errs on the side of convenience. Alternatively a record may be made, but the defect regarded as *'not safety of flight'* or *'not major defect'* and not considered sufficiently serious to report to aviation regulators, either voluntarily or as part of mandatory requirements. [29,66] Lastly, as aviation regulations impose strict guidelines on how aircraft defects are defined, must be reported, investigated and dealt with, some leaks may actually be reported to aviation regulators. [29] These reports tend to cover the more significant events, but not always so. However, with substantial under-reporting and a culture of complacency between operators and regulators, no aviation regulatory authority can in reality consider that the reports they receive from the industry represent anything other than a very small tip of a very large iceberg of leak or exposure events. [66]

From review of available sources and reported and accessible information, it is apparent that only a small fraction of the known incidents are reported. [29] Evidence is available that suggests that there are a substantial number of leak incidents on airplanes, especially on certain models of aircraft. [29] Many of these leaks go unreported to aircraft operators. Of those leak incidents that are reported to aircraft operators, many are not reported to regulatory authorities. Of those leak incidents that are reported to regulatory authorities, not all are added to relevant databases. Ultimately, only a very small number of leak incidents are investigated fully. [29]

The aviation industry suggests frequently that as oil leaks are so rare, it is highly unlikely to monitor the air during a fume event, with such events termed *'episodic'* and *'infrequent'*. [10] The view that such events are rare is based on the flawed reporting process and likely to influence the effort given to acquiring accurate data during such contaminated air events. Therefore, it is necessary to review the air quality studies undertaken to date to determine if this hypotheses is correct, if studies are indeed appropriate for detecting contaminated air and then determine what should be done.

5.3 Aviation air quality monitoring studies

During the last sixty years there have been a number of studies carried out in relation to aircraft air quality and chemical contaminants entering the cabins of aircraft. Some of this research is not available in the public domain, and in some cases, it may be difficult to critically examine its findings.

A review of the various studies will be undertaken; however the quantification of the various substances will not be reviewed except in specific cases. The reviews will look at the substances found, any health studies or epidemiological data taken at the time and the techniques and circumstances surrounding these studies.

Studies on contamination of the aircraft cabins began in the late 1970s. Such studies tend to be of two types:

- Studies looking at the possible contents of aviation engine oils and other products.
- Studies looking at the chemical content of air in aircraft during flight.

Additionally there have been a number of papers written reviewing the various air quality studies.

5.3.1 Studies on aviation oils

A summary of studies on jet oils are shown in Table 5-1. These findings are discussed further below.

Table 5-1: Studies on aviation oils

Reference, first author	Year	Comment	Monitoring for	Chemicals present
Treon [39,40] USAF	1954	Inhalation toxicity Investigation of decomposition of lubricants at elevated temperatures	Toxic effects of decomposition products of heated synthetic engine oils	Fogs formed at 600°F (315°C) or above were much more toxic than those formed at 400-550°F (204-288°C). Products of thermal decomposition are far more toxic than undecomposed material. Esters - aldehydes, carbonyls, CO and undecomposed particulate matter. TCP - free cresols,

Reference, first author	Year	Comment	Monitoring for	Chemicals present
				undecomposed TCP and CO
Callaway UK Ministry of Supply [67,68]	1955	Report on toxicity of synthetic lubricating oils and some of their components – unpublished (Unsighted/refer Esso report, 1956)	Toxic (inhalation) effects of decomposition products of heated synthetic engine oils	Fogs generated from oils heated to 572°F (300°C)
Siegel [74] US Navy	1965	Inhalation toxicity study of triaryl phosphate hydraulic fluids containing tricesyl , trixylenyl and trialkyl phosphates.	Toxic effects of long-term inhalation to triaryl phosphates	Highly suggestive that components other than ortho tolyl groups have significant toxicity or are capable of synergizing or potentiating other triaryl phosphates
Levenson, Industrial Biology Labs Inc, [69,70] Esso	1967	Laboratory analysis to determine LC50 Esso Turbo oil 2380/Esso Turbo oil 15	Toxic substances of inhalation of heated engine oils	Thermally derived products from both oils had same order of toxic effect & those derived at 500°F (260°C) were far less toxic than 700°F (371°C)
Douglas Aircraft Co. [71,77]	1969	Bleed air tests simulating engine oil leak to determine purity of air to relieve restrictions	CO, CO_2, total hydrocarbon & oil breakdown products and aldehydes,	Insignificant amount of contamination, less than 15 ppm CO. Results to be viewed with caution due to methodology problems and restricted to 600°F (315°C)
Pratt and Whitney [72]	1969	Bleed air purity tests on JT3D-3B and TF33-P7 engines	Total oil breakdown products	Total hydrocarbon content was lower than allowable limit for individual substances
Paciorek [78] USAF	1979	Laboratory simulation of thermal degradation of oils and fluids.	Organic contaminants	Hydrocarbons, carbonyls, formaldehyde, acreolin, formates
Crane [81] FAA	1983	Toxicity study in rats and chickens to six commercially available jet oils.	Toxic effects of CO	Incapacitation considered to be due to carbon monoxide
Callahan [83] US Navy	1989	Investigation of fluids and oils to form TMPP	TMPP	Exxon 2380 formed large quantities of TMPP along with one other oil of MIL-L 23699C standard
Wizniak [79] NTSB	1984	Ground level based analysis of turbine oil contamination	Oil by-product contamination and effects	Unburned hydrocarbons, CO, CO_2, NO_2. No breakdown products of oil, no toxic threat
Dickey [86] Textron Lycoming	1989	Laboratory analysis of synthetic oil on hot surfaces up to 370°C.	Oil compounds & breakdown products	Substances of oil identified with no breakdown products identified up to 370°C
Lipscomb [88] USAF	1995	Rats exposed to oil fumes.	Toxic effects of Triaryl phosphates	Neurotoxic impact associated with inhalation of TCP

Reference, first author	Year	Comment	Monitoring for	Chemicals present
Fox [89] Honeywell	1996	Laboratory studies of 6 oils heated to 370°C.	aldehydes, acrolein, SVOCs, VOCs	Variety of VOCs, SVOCs
van Netten 1,2 [90,91] UBC, Canada	2000	Laboratory analysis of two jet oils on hot surfaces to 525°C.	CO, CO_2, NO_2, HCN, OPs and volatiles	CO_2, CO (above 100 ppm). TCP in bulk oils and air, Volatiles
van Netten [92] UBC	2000	Laboratory analysis of two jet oils on hot surfaces to 525°C.	CO, CO_2, NO_2, HCN, OPs and volatiles	CO_2, CO (above 56 ppm), HCN, TCP, PAN
Marshman [93] DERA, UK MOD	2001	Examination of thermal degradation products of used and unused oils exposed to 350°C and 450°C.	Mist and vapors, CO, CO_2, NO2, formaldehyde	CO, carboxylic acids, ketones, primary degradation products of ester base stock (carboxylic acid mono and bi- esters of trimethyloprpane and pentaerithritol), formaldehyde, TCP, diphenylamines
Fox [97] Honeywell	2001	Thermal decomposition studies (400°F (200°C), 700°F (371°C)) of 6 oils undertaken by Honeywell, Shell, BP, ExxonMobil aviation lubricants.		CO, VOCs, aldehydes, SVOCs, TCP (isomers other than TOCP), heavy hydrocarbon matrix, PAN.
Johnson, Forster USAF [73]	2002	Examination of degradation of phosphate esters	TCP, TPP, tri(tert-butylphenyl) phosphate	Metal catalyzed degradation of phosphate esters confirmed
CAA† [94,95] CAA, UK	2004	Laboratory analysis of unused and contaminated BAe 146 cabin air supply ducts.	Oil breakdown products	Contaminated ducts contained short chain organic acids and carbonaceous material (includingTCP/OCP isomers) consistent with the pyrolysis products of aircraft engine oil.
Kibby [103] DSTM, Australia	2005	Analysis of additives in engine oils.	TCP, amine antioxidants	PAN, DODPA, TCP ortho isomers consist of almost exclusively mono ortho isomer
Solbu [102] NIOH, Norway	2007	Development of a GC/MS method for analysing trialkyl and triaryl organophosphates.	Organo-phosphates	Trialkyl phosphate, triphenyl phosphate (including o-, m- and p-isomers of TCP)
De Nola [65] Dept of Defence, Australia	2008	Determination of ortho-cresyl phosphate isomers of tricresyl phosphate	TCP	Ability to analyse for the mono-o-cresyl isomers of TCP.

† Refer Marshman 2001 [93] as part source of this report.

A 1954 USAF study, of which parts were sponsored by Monsanto Chemical Company, investigated toxic effects of animals exposed to mists consisting of heated synthetic jet engine oil meting MIL-L-7808 standard. The toxicity was found to come from the breakdown of the principle ingredient, the base stock di-2-ethylhexyl sebacate, while the presence of a very low level of TOCP contributed little to the toxicity. The fogs produced pneumonitis and degenerative changes in the brain, liver and kidneys. In the case of the esters, aldehydes, carbonyls, CO and undecomposed particulate matter were found in the atmosphere, while in the case of the TCP, free cresols, undecomposed TCP and CO were found. Fogs formed at 400-550°F (204-288°C) were *'much less toxic than those formed at 600°F (315°C). The products of thermal decomposition are much more toxic than the undecomposed material.'* [39,40] Fatalities were noted to particularly increase in animals exposed to the mists generated from the oils exposed to temperatures of 700°F (371°C) over those of 400°F (204°C). Decomposition temperatures of the phosphates 1050°F (565°C) were notably higher than for the esters.

According to a 1956 Esso memo, [68] an unpublished and unsighted British Ministry of Supply (predecessor to MOD) study heated two synthetic engine oils to 572°F (300°C) and exposed animals for up to six hours and human volunteers for two hours to the fog/oil vapours in a study chamber. [67] The fogs produced varying degrees of mucous membrane irritation and some respiratory difficulties in the animals with all animals returning to normal after 24 hours and were healthy after fourteen days. The majority of human volunteers (exposed to *'similarly generated oil vapors'* in 10% disbursement of oil per litre of air compared to animals) complained of *'transient dryness of the throat and slight irritation of the nose, with occasional slight eye irritation, sniffing and slight headache. There were no complaints of nausea and all were able to carry out normal functions.'*

In 1965, US Navy studies investigated long-term and repeated inhalation exposure studies to triaryl phosphate fluids containing a mixture of tricresyl phosphates, trixylenyl phosphates and other trialkyphenyl phosphates. [74] The studies found it *'highly suggestive'* that components other than ortho-tolyl (o-cresyl) groups have significant toxic activity or are capable of synergizing or potentiating the toxic effects of triaryl phosphates.

A 1967 study undertaken for Esso Research and Engineering Company and Humble Oil, [69,70] exposed animals via inhalation to Esso Turbo oil 15 and 2380 that had been heated to 500°F (260°C) or 700°F (370°C) to determine the lethal concentrations. The animals exhibited paralysis in the hind quarters while autopsies revealed *'gross changes suggesting severe irritation of the respiratory tract consisting of edema, inflammation and gross hemorrhage into the bronchioles and alveoli.'* [69] The apparent cause of death was deemed a *'result of severe irritation to the respiratory tract.'* The techniques used by Treon [39,40] were deemed inadequate by Levenson. [69] The report concluded that the temperature within the chamber (80-55°F or 27-13°C) was found to significantly affect the results; the thermally derived products from the two oils had *'the same order of toxic effect'*; rabbits were least tolerant to the exposures and *'products thermally derived from either sample at 500°F (260°C) were less toxic than those derived at 700°F (370°C)'.* McDonnell Douglas upon reviewing the report, compared the results to the 1954/55 Treon USAF studies and reported to Humble Oil that they *'found a noticeable difference between the results'*, even though the testing conditions had been the same. [70] They advised that the oils studied in the 1967 Esso study (Esso 2380/Esso 15) were improved oils over those used by Treon (Ws-2211) and thus they *'would expect that they have no higher level of toxicity than WS-2211.'* McDonnell Douglas therefore reported it was 'concerned about this' and would like Humble Oil's opinion before pursuing the matter further. [70]

In 1963, Douglas Aircraft Company commenced specific investigations into *'clean air'* [75,76] of which the primary objective was to *'determine the quality and quantity of the contaminants in engine bleed air when simulating an oil leak'* in jet engines. The program was thought to *'help relieve stringent self-imposed restrictions on bleed air system design.'* [65] Tests were run on a Pratt and Whitney JT3D engine in 1969 at Edwards Air Force Base at bleed air temperatures up to 600°F (315°C) to determine engine oil (Type II, Esso 2380) leakage rates and engine companies were surveyed regarding oil leakage rates for various types of failures along with the petroleum industry regarding the standards on toxicity. [71,66,77] The report found that *'much less contamination than anticipated'* was found and *'should be viewed with caution'* with altered procedures suggested. [71] The preliminary report associated with the final report noted problems and observations such as: the oil leaking out the fan ducts; oil droplets pass by bleed air port so fast that decomposition will not have taken place; 600°F (315°C) is likely not hot enough to assure decomposition and *'additional runs with the present set up would be a waste of time.'* Further Douglas tests (unavailable for review) investigated oil exposed to temperatures of 700°F (371°C) with changes in methodology as aircraft pneumatic systems could be simplified if it was shown that it was safe to take bleed air at high temperatures. [66]

In 1969, Pratt and Whitney undertook a *'bleed air purity test'* for the JT3D-3B and TF33-P-7 (C-141 aircraft) engines. [72] The bleed air temperatures for the TF33-P-7 were 560°F (293°C) at the twelveth stage and 755°F (400°C) at the sixteenth stage bleed port. The total ppm for the total oil breakdown products was found to be less than the allowable limit for each individual substance and therefore individual compounds were not analysed.

In 1979, a series of lubricating oils and hydraulic fluids were examined by the USAF for their potential to contaminate cabin air. [78] This test confirmed that tests simulating line rupture with fluid spilling onto a hot 450°C metal surface in the presence of air resulted in excessive fluid degradation, with significant concentrations of hydrocarbons, carbonyls and alcohols produced, including formaldehyde, acrolein, formic acid and formates.

Studies by the US Transportation Board (NTSB) in April 1983, following a number of fatal accidents, investigated whether a cracked engine oil seal in a turboprop engine might allow *'toxic or anaesthetic by-products of the oil to enter the aircraft's environmental system.'* [79,80] The NTSB partnered with the aircraft engine and oil manufacturers to carry out test runs on the ground using Exxon 2380 lubricating oil in a Garrett TPE 331 turboprop engine in Arizona in 1981. The NTSB noted that:

- *if identified, such exposures could compromise flight safety and could be a risk on all bleed air aircraft. In most of the trials, liquid contaminants were removed with a glass wool filter prior to the sampling port.*

The NTSB study concluded that *'the hypothesis concerning subtle pilot incapacitation due to engine oil contamination of the bleed air supply ...is completely without validity.'* The report noted that in some of the trials, a glass wool filter removed liquid and semi-volatile contaminants before the contaminated air reached the sampling port. However, a companion study published by the FAA acknowledged *'the (NTSB) approach did not eliminate the possible presence of an additional [chemical] component with significant animal toxicity'* and *'with an unfiltered [bleed airline, a significant toxicity could be associated with breathing the oil mist.'* [81] The NTSB report, which noted the results were applicable to aircraft using this particular turboprop engine only (not used on larger commercial aircraft), did however cover the possibility of sensitization when stating:

- *'There are instances in which chronic or repeated exposure may sensitize a person to certain chemicals so that concentrations in the ppb range may elicit an acute hypersensitivity type reaction.'* [79,80]

That same year, the FAA conducted a companion animal toxicity study exposing rats and chickens to unfiltered engine oil smoke (six different oils) in an unpressurized environment and measuring the level of CO gas along with the animals' *'time to incapacitation and 'time to death.'* [81] They compared their data to those collected in previous studies of rats exposed to CO alone and concluded that CO was the most toxic component of the oil aerosol. On that basis, the FAA echoed the NTSB conclusion that the pilots were not incapacitated because of exposure to oil fumes, essentially because the oil was not significantly toxic - aside from CO - and the CO data alone did not explain incapacitation. However, the FAA noted that *'the (NTSB) approach did not eliminate the possible presence of an additional [chemical] component with significant animal toxicity'*; presumably given that the NTSB had filtered the oil fumes prior to measuring them in a number of the trials. [82]

US Navy studies in 1989 found that large quantities of the neurotoxic TMPP could be formed quickly under laboratory conditions when Exxon 2380 was heated, in addition to one other MIL-L-23699C synthetic oil, yet at lower levels. [83] A number of recommendations were made including the need for research of the overall toxicity of combined combustion by-products rather than individual chemicals; Exxon 2380 be withdrawn from the Navy inventory and all polyol ester based oils be checked for TMPP formation. TMPP can occur with *'thermal decomposition of an aircraft engine oil containing fatty acids of trimethylol propane (TMP) and tricresylphosphate (TCP).'* [83,84]

Base stocks using TMP esters in synthetic oils utilizing TCP are relevant here, particularly at temperatures between 250°C and 750°C. [85]

A 1989 study by Dickey and Wilson of Textron Lycoming investigated contaminants arising from air flowing over a vessel of heated synthetic oil. [86] The oil was of a MIL-L-23699 specification, heated at 250°, 450° and 700°F (120°, 230° and 370°C), and from a cabin air sample taken from an un-named aircraft over the UK with a *'slight odour of oil'*. Results indicate that the oil found in the cabin was not chemically altered from the oil in the engine.

In 1990, a Discussion Paper on developing a limit for total organic material in cabin bleed air was prepared for the SAE E31 Cabin Air Sub Committee. [59] This paper noted that it had long been recognised that contamination of the cabin bleed air by engine generated organic material may occur as a result of fuel or oil leaks or thermal degradation of these contaminants and or elastomer seals. Various ways of expressing such contamination were discussed with a final recommendation made that the maximum allowable concentration of total organic material should be in the order of 0.1 parts per million by weight, or 0.2 parts per million by volume (0.2 ml/m^3). This is an exceptionally low level, compared with the conventional exposure standard for low toxicity oil mists (at 5 mg/m^3 for mineral oils only).

A 1991 Datachem report for Allied Signal Aerospace suggested breakdown of engine lubricant by excessive heat probably did not occur. [87]

A 1995 USAF report investigated inhalation toxicity of vapour phase lubricants, recommending caution when using triaryl phosphate vapour phase lubricants. [88]

A 1996 study by Allied Signal undertook laboratory studies of six oils heated to 370°C. A variety of VOCs and SVOCs were identified. [89]

A 2000 report by van Netten and Leung investigated the release of CO, CO_2, NO_2, HCN, and volatiles under laboratory conditions at 525°C from two jet oils, measured using gas chromatography (GC). [90] The aim was to determine if the neurotoxic agents tricresyl phosphates (TCPs), or trimethyl propane phosphate (TMPP) would be present or formed. TMPP was not found in these experiments. Some CO_2 was generated along with CO, which reached levels in excess of 100 ppm. HCN and NO_2 were not detected. The presence of TCPs was confirmed in the bulk oils and in the volatiles. GC compositions of the two bulk oils and their breakdown products were almost identical.

A 2001 report by van Netten and Leung investigating pyrolysis products from an engine oil noted that the oil was an important source of carbon monoxide, volatiles, and organophosphate constituents, including phenyl and tricresyl phosphates. [91] The authors suggested that during oil leaks, localised condensation products in ventilation ducts became re-mobilised when cabin heat demand increased, and could account for mid-flight incidents. An additional similar 2000 study by van Netten identified TCP, PAN, along with carbon monoxide. [92]

A previously unavailable 2001 study by Marshman of the UK Defence Evaluation and Research Agency (DERA), [93] undertaken on behalf of the UK CAA (listed as *'Restricted Commercial'* with *'data used is the property of BAe Systems'*) and utilized as the basis of a CAA sponsored DSTL report in 2004, was obtained five years later under the UK Freedom of Information Act. [94,95] Two samples of an unidentified unused and used (said to have been involved in a *'health related incident'*) ester based lubricant were heated to 350°C and 450°C and released into an atmospheric pressure airstream so as to analyse the reaction products. The measured mist remained mainly as the unchanged oil/additive products (TCP isomers: tri-para, di-para, mono-meta, di-meta, mono-para, tri-meta with other phosphate peaks detected at low levels) with some thermal degradation from the lubricants ester base oil, namely carboxylic acids, CO, some ketones, decanoic/octanoic acids and carboxylic acid mono- and bi- esters of trimethylopropane and pentaerithritol. No changes in the phosphate esters were noted (TCP) and phenyl-1-napthylamine and dioctyldiphenylamine were detected in all cases. It was suggested that significant quantities of degradation products would not be formed and released into the compressor immediately after an oil leak. The oil analyzed was BP 2380, [96] and additionally it is understood to be the only oil used by civilian operations using the trimethylopropane (TMP) base stock. It was noted that a real oil leak would be exposed to increased rate of oxidation given the *'reduced'* partial pressures, resulting in increased oxidation products. However, the residence time of the oil at high temperature was noted as 0.1 s said to be a *'short time'* resulting in some thermal degradation. The Marshman study was not peer reviewed and failed to outline the methods or techniques used to any great detail, additionally many compounds from the GCMS analysis had not been labelled or identified.

A 2001 thermal decomposition study of six synthetic oils at 400°F and 700°F (204°C and 371°C) was undertaken by Honeywell and three major oil manufacturers (BP, ExxonMobil, Shell). [97] CO, VOCs, aldehydes, SVOCs, TCP isomers other than TOCP and PAN were identified along with a *'hydrocarbon matrix'* described as *'a broad mix of very heavy tar like co-eluting compounds'*. The hydrocarbon matrix was noted to elute over a twenty minute time interval. Little thermal decomposition was noted at the lower temperatures; however a wide range of decomposition products were noted in the higher range temperature, including significantly greater concentrations of the TCP isomers (other than the TOCP).

A USAF study in 2002 found that TCP and T-BPP provided a qualitative understanding of the metal-catalyzed degradation of phosphate esters. In the absence of a metal surface, the primary degradation product is cresol and significant amounts of the phosphate ester remain after 24 hours at 450°C. In the presence of the metal, when bound oxygen is plentiful, cresol is the primary product. If there is less oxygen available, additional products such as tolyl-TCP are formed. Once formed, these products further decompose to give lower molecular weight products. In the case of meta isomers of TCP or t-BPP, further reaction leads to the formation of fused-ring aromatic compounds. [73]

A UK CAA 2004 report conducted by the Defence Science and Technology Laboratory (DSTL) at Porton Down evaluated the cabin air quality issue in two parts. [94,95] The first part analysed the DERA Marshman report [93] and identified the constituents and pyrolysis products of the aviation oils. These were reported under four main categories: the two base stock trimethylolpropane (TMP) and pentaerythritol (PE) esters *'making up the lubricant itself'*, the additives cresylphosphates (TCP) and N-phenyl-1-naphthylamine (PAN) and relatively low molecular weight organic acids, esters and ketones *'which are reported as thermal breakdown products of the lubricant esters or contaminants present after manufacture.'*

Organic acids including the *'small quantities'* of decanoic and octanoic acids found were *'known to be irritants and could produce the stinging of the eyes and nasal membranes as reported. Organic acids also have characteristic odours which are described by some as "acrid", "old socks" …and are not dissimilar to the descriptions of cabin odours given in some of the incident reports.'* [94,95] The *'Toxic Effects of Contaminants of Pyrolysed Aviation Lubricant'* listed in the CAA/DSTL report are shown in Table 5-2 below.

Table 5-2: Toxic Effects of Contaminants of Pyrolysed Aviation Lubricant

From [94,95]

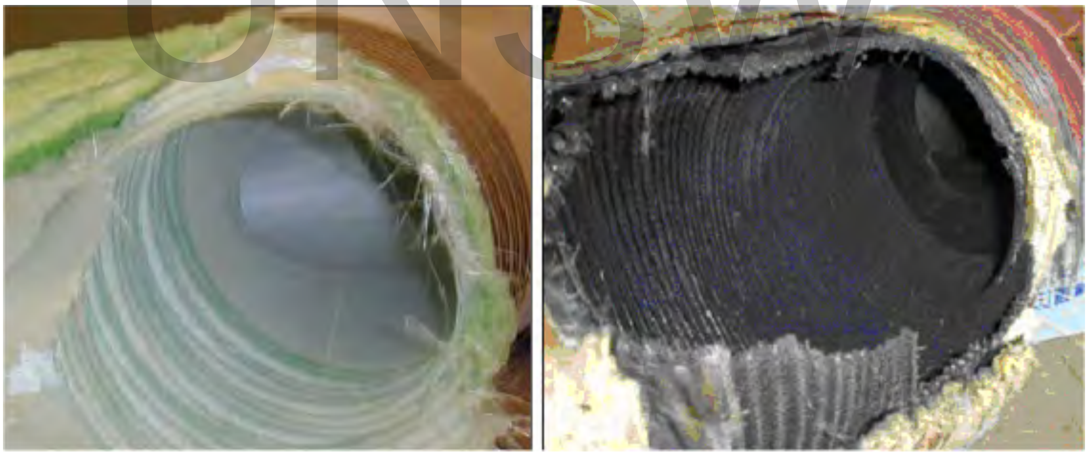
Contaminant	Toxic Effect
Octanoic, Decanoic acid	Severe irritation of eyes and throat and can cause eye and lung injury. Cannot be tolerated even at low concentrations [98]
N-Phenyl-alpha-naphthylamine	No acute toxic effects listed. Suspect mutagen and carcinogen - tumorigenic in lung, thorax,
4,4'-dioctyldipheylamine Tricresyl phosphate (mixed isomers)	When heated to decomposition it emits toxic fumes of NOx. Can irritate the eyes on contact, can irritate the nose and throat, can induce nausea, vomiting, diarrhoea, stomach pain and loss of appetite. [98]
Tri-m-cresylphophate Tri-p-creyslphosphate	Vapours may irritate eyes but only at high concentrations. Effect on workers producing tritolylphosphates is characterised by perivascular form of neuritis, decreased activity of plasma cholinesterase and chronic gastritis with deficient secretion, toxic encephalopathy, hypothalamic syndrome, polyneuritis ... Does not produce typical syndrome associated with cholinesterase inhibition ... meta and para isomers are relatively inactive.

The report found that *'no single or set of components' identified by Marshman could 'be identified which at conceivable concentrations would definitely cause* *the symptoms reported in cabin air quality incidents'.* [94,95] However the presence of short chain organic acids *'could cause irritant effects',* despite the fact that *'no quantitative information on the concentrations in inspired air necessary to cause irritancy was available.'*

Additionally, the report stated that *'in the event of oil leakage there is the opportunity, therefore, for the pyrolysis products of engine lubricant/fuel to enter the cabin air supply and exert toxic effects on both passengers and crew.'* Importantly the fumes from engine oil leaking into the bleed air system and hence into the cabin air supply, was the *'most likely cause'* of the incidents and *'no weight of evidence indicating that other causes were involved'* was found. One of the recommendations was that *'The effect of hypoxic conditions on the toxicity of oil pyrolysis products should be investigated.'* [94,95]

Part 2 of the report evaluated unused and contaminated cabin air supply ducts (seeFigure 5-1) removed from two different BAe 146 aircraft after flying for long periods. [94,95]

Figure 5-1: Uncontaminated and contaminated ducting



Photographs taken from [95].

The conclusions drawn were that:

(i) the unused ducting contained no detectable toxic compounds;

(ii) ducts extracted from airplanes in operation *'were contaminated with a carbonaceous material containing chemicals entirely consistent with the pyrolysis products of aircraft engine oil* , that is 'aviation lubricant and its additives*'* ;

(iii) a variety of compounds were identified, as well as TCP isomers including TOCP, which was found in the used ducts in concentrations higher than in the parent oil (however, analysis for the more toxic orthocresyl isomers was not carried out).

The ducting was removed some weeks before the analysis was carried out and it is highly probable that volatile materials would have evaporated in the intervening period. The TCP isomers found in the used ducting were recorded at a maximum of 1 μg/g ortho isomer, 68.1 μg/g meta isomer and 8.1 μg/g para isomer. The isomer levels identified in Exxon turbine oil were identified at 0.002 μg/g ortho isomer, 0.138 μg/g meta isomer and 0.044 μg/g para isomer. This confirms the statement that the isomers found in the ducting are at higher levels than the parent oil (indicating that other materials are removed by combustion or pyrolysis) and that residual contamination can occur.

Over forty different chemicals contained in oil breakdown products were acknowledged, many with no published toxicity data (including the base stock esters TMP and PE), so it was not possible to determine how these substances could cause or contribute to the reported effects. *'Any or all of the small molecular compounds discovered could possibly be responsible for the symptoms experienced by flight crew, but the most likely are the short chain organic acids such as pentanoic and valeric acid, acting as irritants.'* While the smaller more volatile molecules were deemed most likely to give *'toxic effects'*, many were reported as having no exposure standards. Potential effects from the volatile compounds encountered in sufficient quantity included effects such as: eye burns or irritation, conjunctivitis and corneal damage; chemical burns to the respiratory tract, respiratory tract irritation, aspiration leading to respiratory swelling and pneumonitis, burning sensation; coughing, wheezing, laryngitis, shortness of breath irritation of mucous membrane; dizziness; systemic effects; headache, nausea or vomiting, with some effects delayed and the toxicological properties of selected substances recognized as not *'fully investigated.'* [94,95]

The report incorrectly assumed the TOCP isomer of TCP was the most toxic, but noted that Marshman may not have found it as *'the very much less sensitive'* GC-MS was used in the DERA studies. The DSTL studies used GC-FDP analysis. [95] Additionally the effects of the base stocks were reported as having no *'information on the toxicology'* available with data from ExxonMobil and it's OPIDN studies relied upon listing the oils as *'practically non- toxic.'* [94,95]

The DSTL was also commissioned to undertake a review of *'Three Reports on the Toxicology of Aviation Lubricant Constituents.'* [99] Data reviewed included studies by van Netten, ExxonMobil and the Australian NICNAS submission to the Australian 1999/2000 Senate Inquiry into cabin air contamination. [90,100,101] The study requires close evaluation, as inaccuracies are present, such as the statement that bulk oil samples do not contain ortho isomers of TCP and the assumption that the ortho isomers of TCP from aviation lubricants had been removed some years ago by modification of the source cresols and manufacturing process. [99]

A 2007 report by Solbu from the National Institute of Occupation Health in Norway developed a methodology for personal occupational exposure assessment to airborne trialkyl and triaryl organophosphates used in hydraulic fluids and synthetic lubricating oils. [102] The methodology utilized active combined aerosol and vapour sampling using a combined fibreglass (for aerosol capture) and sorbent (for vapour capture) and gas chromatography/mass spectrometry (GC-MS) techniques. [102] Importantly, the GC-MS methods used in this study show a clear separation of ToCP, TmCP and TpCP (only TCP standards available and utilized) isomers and other OPs. The aryl phosphates were recovered solely from the filter, while the alkyl phosphates were recovered from both adsorbent and the filter. In operational studies in a mechanical workshop where the jet oil was being used, total TCP isomers (meta and para) were reported at concentrations of 0.24 and 0.28 mg/m^3. The corresponding oil mist and vapor concentrations were in the range 0.39–6.6 mg/m^3 and 0.26–23 mg/m^3, respectively. The measured amounts of TnBP (tri butyl phosphate) in the air samples were 0.061 and 0.072 mg/m^3, with recovery solely from the glass fibre filters.

A 2008 Australian Defence study analysed additives in a number of engine oils. [103] Diphenylamines, PAN (N-Phenyl-alpha-naphthylamine) and DODPA (dioctyldiphenylamine) were reported at 1% each, while the TCP o-cresyl isomers were found to be almost exclusively as the more toxic mono-o-cresyl isomers with the tri-ortho isomers shown to be insignificant.

Importantly, all structural isomers of TCP, from aircraft engine oil were identified and quantified by GC-MS and separated by GC with the exception of the omm and oop isomers. The o-cresol (mono ortho isomer) content of TCP in aircraft turbine oil samples manufactured since 1999 was found to be below 50 mg/kg. For practical purposes, in the oils analysed, the ortho isomers were represented by the mono-ortho (oxx) form at concentrations of 13–150 mg/kg. The levels of tri-ortho (ooo) and di-ortho isomers (oox) were found to be below levels of detection. *'The toxicity of TCP should be based on the mono-o-cresyl isomer content rather than on the tri-o-cresyl phosphate content. The concentrations of the mono-o-cresyl isomers can be determined by calculations based on the precursor o-cresol isomer content of TCP or by direct GC analysis of TCP.'* [103]

5.3.2 Air quality studies

A summary of known air quality studies is shown in Table 5-3. Selections of these findings are discussed further below. There are additional air quality studies, such as a 737 Boeing study and a 1974 Lockheed study, however these have been unavailable for review and as such are not part of this survey. [104,105,106]

This review does not list details of studies looking at relative humidity, temperature, ventilation and a number of other variables.

A 1983 USAF study reported that over a ten-year period to 1980 there were 89 incidents of smoke or fumes in the flight deck during flight. [7] No monitoring was undertaken, however the sources of the fumes were listed as mostly *'organic petroleum derivatives'*, which caused a multitude of symptoms including CNS dysfunction and upper airway irritation. Organic hydrocarbons were identified as the cause in most of the incidents, including CO, oil, fuel, hydraulic fluids, acetone with a mixture of substances in some cases.

Table 5-3: Air Quality Studies

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Table 5-3: Air quality studies

Reference, first Author	Year	Aircraft type	Crew status	Monit-oring under-taken	Studies specific to incident events	Studies related to general air quality	Monitoring under-taken during contam-inated air events	TCP found	Other	Oil identified as source of problem?	Health endpoints investigated * = not at time of monitoring	Air accep-table
Rayman [7]	1983	Military	FC	No	Yes				Investigations found variety of organic hydrocarbons as cause	Yes in 43% of identified cases	Cause and symptoms related to smoke/fume events collated	
Kelso [107]	1988	Military		Yes	Yes	No	No	Yes	Turbine oil vapours	Yes	No	
Malmfors [195]	1989	DC9 MD80		Yes	No	Yes	No	No	CO_2, RSP	No	No	
Alaska Airlines [108]	1990	MD80	CC	Yes	Yes	No	No	No	CO_2,VOCs	No	* Telephone interviews and medical records reviewed for several	Yes
O'Donnell [196]	1991			Yes	No	Yes	No	No	CO_2, RSP, formaldehyde	No	No	
Wilkins [109]	1991	146		Yes	Yes	No	No	No	Analytical problems	No	No	
Fox [48]	1991	146		Yes	Yes	No	No	No	Breakdown products of oil	Yes	No	
Vasak [110]	1992	146		Yes	Yes	No	No/After event	No	Oil mist	Yes	No	
Nagda [113]	1992	727, DC10 747, 767, DC9, 757 737, L1011		Yes	No	Yes	No	No	O_3, CO_2, CO, particulates	No	No	Yes
Rhyder [111]	1992	146		Yes	Yes	No	No	No	Unsuitable methods	No	No	

Reference, first Author	Year	Aircraft type	Crew status	Monit-oring under-taken	Studies specific to incident events	Studies related to general air quality	Monitoring under-taken during contam-inated air events	TCP found	Other	Oil identified as source of problem?	Health endpoints investigated * = not at time of monitoring	Air accep-table
Domnick Hunter [112]	1992	146		Yes	Yes	No						Yes
NIOSH [115]	1993	MD80, 727, 737	CC	Yes	Yes	No	No	No	CO_2, CO, O_3, particulates, VOCs	No	* Crew illness records/medical reports reviewed	Yes
CCS [116]	1994	DC9, 727, MD80, 757		Yes	No	Yes	No	No	CO_2, CO, O_3, VOCs, particulates	No	No	Yes
Currie [119]	1995	146		Yes	Yes	No	No	No	No	No	No	Yes
Allied Signal [122]	1996	146	FC and CC	Yes	Yes	No	No After event	No	Oil contamination CO_2, NOx, CO, hydrocarbons	Yes	*adverse effects/odours reported	
Lee G [123124]	1997	146		Yes	Yes	No	No	Yes	Range of hydrocarbons	Yes	No	
Fox [125]	1997	146		Yes	Yes	No	No No	Yes*	CO, range of VOCs; TBP, SVOCs, other phosphate isomers	Yes	No	Yes
Spengler [134]	1997	777		Yes	No	Yes	No	No	CO, NO_2, O_3 VOCs, Particulates	No		Yes
Dechow [121]	1997	A310, A340		Yes	No	Yes	No	No	VOCs, formaldehyde	No	No	Yes
van Netten [135]	1998	146	FC and CC	Yes	Yes	No	No 1 day after	No	Range of VOCs	Yes	* Variety of symptoms/odours reported. Consistent with low level CO, Irritants, volatiles, neurotoxins and TCP	

Reference, first Author	**Year**	**Aircraft type**	**Crew status**	**Monit-oring under-taken**	**Studies specific to incident events**	**Studies related to general air quality**	**Monitoring under-taken during contam-inated air events**	**TCP found**	**Other**	**Oil identified as source of problem?**	**Health endpoints investigated * = not at time of monitoring**	**Air accep-table**
Sleigh [136]	1998	146		Yes	Yes	No	No	No	Various VOCs	Yes	No	Yes
Haghighat [138]	1999	A320/340, DC9, 767		Yes	No	Yes	No	No	CO_2	No	No	
Lee [139,140]	1999	747, A330, A340	CC	Yes	No	Yes	No	No	CO_2, CO, O_3, NO_2, SO_2, RSP Particulates	No	* Survey questionnaires reported variety of symptoms	Yes
ASHRAE CCS [142]	1999	777	CC	Yes	No	Yes	No	No	O_3, CO_2, CO, VOCs, formaldehyde	No	Surveys completed by cabin crew and passengers	Yes
Mersk [146]	2000	737		Yes	Yes	No	No After event					
Qantas [147]	2000	146		Yes	Yes	No	No	Yes	Yes	Yes	No	Yes
Ross [144]	2000	777 747		Yes	No	Yes	No	No	VOCs, aldehydes, ketones		No	
Dumyahn [145]	2000	757, 767, 737, 747, DC10, 320 DC9, 300 MD80		Yes	No	Yes	No	No	CO_2, O_3, CO, VOCs, NO_2, Particles …	No	No	Yes
Honeywell [152,153, 154, 155,156]	2000	146		Yes	Yes	No	No	Yes	Wide range of VOCs, SVOCs, Hydrocarbon matrix, CO, formaldehyde TPP, Oil contaminants,	Yes	No	
Nagda [157]	2001	767, 737, 747		Yes	No	Yes	No	No	O_3, CO_2, CO, aldehydes, particulates, VOCs,SVOCs	No	No	Yes

Reference, first Author	Year	Aircraft type	Crew status	Monit-oring under-taken	Studies specific to incident events	Studies related to general air quality	Monitoring under-taken during contam-inated air events	TCP found	Other	Oil identified as source of problem?	Health endpoints investigated * = not at time of monitoring	Air accep-table
BAe [158]	2001	146		Yes	Yes	No			Various, used engine oil, MJOII, Exxon 2380			
British Airways BRE [159]	2001	757		Yes	Yes	No			Oil compounds			
Waters [160]	2002	Variety		Yes	No	Yes	No	No	O_3, CO_2, CO, RsP, NO_2, VOCs, formaldehyde SVOCs	No	No	Yes
Lindgren [161,162, 163,164]	2002	767	CC	Yes	No	Yes	No	No	CO_2, RspP, O_3, NO_2, formaldehyde	No	* Surveys completed by cabin crew	
GB Airways [165]	2003	A320	FC & CC	Yes	Yes	No	No	No			Questionnaires completed by crew	Yes
BRE [166]	2003	737 146		Yes	No	Yes	No	No	Wide variety of VOCs, carbonyls, CO, CO_2, NO2, SVOCs, UFP	No	No	Yes
EU Cabin Air [168]	2003	Variety	FC & CC	Yes	No	Yes	No	No	CO_2, CO, O_3, VOCs, SVOCs, UFP, Pm	No	Questionnaires completed by crew listing symptoms and perceptions	Yes
Spicer [172]	2004	MD80 737 757	FC & CC	Yes	No	Yes	No	No	O_3, CO, CO_2, VOC & fine px, SVOCs	No	Survey - proportion of crew and passengers	
CAA [94,95]	2004	146		Yes	Yes	No	No	Yes	TCP in used ducting	Yes	No	
HEACE [179,180]	2005	A330, A340	FC & CC	Yes	No	Yes	No	No	CO_2, CO, VOCs	No	Surveys completed by crew & limited physiological testing	

Reference, first Author	Year	Aircraft type	Crew status	Monit-oring under-taken	Studies specific to incident events	Studies related to general air quality	Monitoring under-taken during contam-inated air events	TCP found	Other	Oil identified as source of problem?	Health endpoints investigated * = not at time of monitoring	Air accep-table
GCAQE [175]	2005 2006	146		Yes	Yes	No	Yes	No	CO -345 flights		No	
Hanhela [177,178]	2005	Military		Yes	Yes	No	No	Yes	PAN, DODPA trialkyl phosphates	Yes	No	No
van Netten [176]	2005	757 146		Yes	Yes	No	No	Yes	TCP in 6 out of 7 acft swab samples, TPP	Yes	No	
Lindgren [199]	2006		FC & CC	No							* Symptoms on flight deck environment	
van Netten [191]	2006	757		Yes	Yes	No	No	Yes	TCP identified in 7 (out of 7) aircraft swab samples	Yes	No	
Molander [192]	2006	146		Yes	Yes	No	No	Yes	TCP identified in 3 (out of 3) aircraft swab samples, TPP, TBP		No	
NIOSH [181]	2006	146, RJ85		Yes	Yes	No	No	No	CO, VOCs	Yes	No	
Lindgren [197,198]	2006		FC & CC	Yes	No	Yes	No	No	CO2, RSP, MVOC, 3 VOCs…	No	Limited medical assessment & surveys completed by crew	
Muir [182]	2007	146 757		Yes	Yes	No	Yes. 1 x B757 flight -minor	Yes	TBP, VOCs, SVOCs, Jet2 oil, UFP	Yes	No	
van Netten [184]	2008	146		Yes	Yes	No	No	Yes	TCP	Yes	No	

Reference, first Author	Year	Aircraft type	Crew status	Monit-oring under-taken	Studies specific to incident events	Studies related to general air quality	Monitoring under-taken during contam-inated air events	TCP found	Other	Oil identified as source of problem?	Health endpoints investigated * = not at time of monitoring	Air accep-table
ICE [187]	2009	Ground based simulators No bleed air, 2 real flights		Yes	No	Yes	No	No	Did not look at contaminants	No	Questionnaires and selected physiological measurements	
GCAQE [193]	2009	747, 777 737, 330 Dash 8 MD80, 146		Yes	Yes	No	No	Yes	TCP identified in 31 (out of 40) aircraft swab samples	Yes	No	
TNO [190]	2009	F70, F100, 777		Yes	Yes	No	No	Yes	TCP identified in 6 out of 10 air samples, TBP in all 10 samples		No	
OHRCA ACER [189]	2009	Variety		Yes	Yes	No	No	Yes	TCP identified in 17 (out of 56) air monitoring samples	Yes	No	
WDR [194]	2009	757,747, 737, A320/319, 146/RJ		Yes	Yes	No	No	Yes	TCP identified in 29 (out of 31) aircraft swab samples	Yes		

Oil was listed as the source (highest rate identified) of the smoke/fumes in 43% of the cases where a cause was identified, CO and hydraulic fluid in 6% and 8% of identified causes respectively. In six cases the crews ejected from their aircraft. The hydrocarbons identified were reported to have known toxic properties all having acute and long-term effects. Smoke/fume events were listed as *'not a rare event and is a clear threat to flying safety.'*

In 1988 Australian RAAF C-130 Hercules were investigated due to concerns and many (increasing) instances of contaminated air reports with the long-term health effects as well as flight safety being the primary concerns. [107] Leaking Avtur fuel was reported correlating with the hydrocarbon background odours. Additionally, a positive indication of turbine oil vapour including TCP was found in air filter bags taken from the air duct system. *'Defective O-ring seals in the compressor extension shaft housing and compressor labyrinth seals may cause some ingress of turbine oil vapour into the air conditioning system.'* No crew data were recorded.

In 1990 Alaska Airlines undertook cabin crew operated air sampling using Vacu-Sampler grab techniques as well as two flights using the Vacu-Sampler, CO, CO_2 sampling and charcoal tube sampling for VOCs. [108] Telephone interviews and review of medical records were undertaken for several crews only. CO_2 and selected VOCs were reported, however below levels which could explain the symptoms reported by crew and passengers. Further consultation was suggested with medical experts in the fields of epidemiology, high altitude, pulmonary and neurotoxicity, rather than monitoring to make the investigation *'both time and cost efficient'.*

A 1991 microbiological study by Pall Europe of an objectionable odour described as '*old socks or cheese*' arising in the APU of a Dan-Air BAe 146 failed to find anything unusual under various conditions of cabin air recirculation. [109] The authors concluded that the APU related odour was not caused by microbial contamination.

A 22 July 1991 memorandum prepared by Richard Fox of Allied Signal Aerospace reports the results of air quality testing for Dan-Air London. [48] This report notes that *'several BAe 146 aircraft are having reports of objectionable odours described as 'dirty socks' or 'musty'.* The report also notes that *'the* *odour appears to be coming from breakdown products of the oil'* and that *'no contaminant appeared to be that great, but they do act in synergism and their combined effect could be enough to trigger the odour complaints.'*

In 1992, Vladimir Vasak, consultant occupational hygienist working with Ansett Australia, investigated APU filter samples and air quality samples from revenue flights. [110] There are a number of procedural and methodological problems with these studies, and in some cases, suitable conclusions could not be made. However, these studies report oil mist levels in the cockpit at 1.5 mg/m^3 and in the cabin at 1.3 mg/m^3, with a similarity noted between the oil in the cabin and Mobil Jet Oil II. The exposure standard for conventional hydrocarbon mineral (not synthetic) oil mist of no known toxicity is 5 mg/m^3, although the applicability of the standard for synthetic oils containing phosphate esters and other toxic ingredients used in aircraft is inappropriate. This study is the first civilian airline report of oil contamination of the cabin, although no tricresyl phosphate was detected.

As a follow up to Vasak's work, the NSW WorkCover Authority conducted an occupational hygiene feasibility study in August 1992. [111] Monitoring consisted of testing whether a gravimetric method (one for dust monitoring) would be suitable and was found to be unsuitable.

In 1992, British Aerospace contracted Domnick Hunter to work with BAe to analyse air samples, which led to the introduction of the BAe cabin air filtration system. [55,112] No toxicity issues were identified; however this work is unavailable for review.

In 1992, a study by Nagda et al (linked to previous 1989 DOT report) investigated air quality on 92 flights. [113] General air quality measurements were only made during routine flights (that is, there were no unusual air quality incidents during the study [1,2,114]). However, carbon dioxide levels (reported at 1756 ppm) were sufficiently high to cause potential comfort problems for passengers. No VOCs or SVOCs were measured.

A 1993 health study of cabin air undertaken by the US National Institute of Occupational Safety on behalf of Alaskan Airlines involved approximately forty flights. [115] It was noted that the acute crew symptoms reported (selected medical files/illness incident reports reviewed) were: more like those reported among US Air Force flight crew members involved in cockpit exposure incidents where oil was most frequently identified as the source of the smoke fume or odour. [7,115] However, it was noted that due to the unpredictable occurrence of air quality incidents and the fact that here were methodological problems with some of the monitoring, it was not possible to arrange for satisfactory monitoring of air quality during an incident. The air quality was, however, deemed acceptable and no reasons could be found for the reported effects.

In 1994, a study by Consolidated Safety Services monitored volatiles and particulates during 35 flights on eight models of aircraft. [116] Air quality measurements were only made during routine flights (that is, there were no unusual air quality incidents during the study [1,2]). While CO_2 was in the discomfort range but not at levels that could cause adverse health effects, [117] all levels monitored were deemed acceptable, however selected techniques were deemed suitable for the industrial workplace environment, rather than applying specific ASTM qualified standards and standards suitable for the unique environment of the aircraft involving an environment utilized by crew and the travelling public. [1,2,114,118]

Two 1995 studies conducted by Ansett Australia collected air for oil mist assessment for fifteen minutes in a plane on the ground following a report of passenger and crew vomiting, and for 360 and 497 minutes on later days in other planes on scheduled services, when no oil leak was reported. [119] Oil mist concentration was reported to be below the level of detect ability (below 0.02 mg/m^3) in all samples. However, oil mists collected in Tedlar sampling bags are likely to coalesce against the side of their container, and when extracted for analysis would only be available in gas or vapour form. As oils tend to have low vapour pressures, the validity of this technique, and the conclusions that can be drawn from them, are *'highly dubious'.* [66] Again, with the exception of a fifteen minute sample after a plane had landed after some passenger and crew symptoms (insufficient for detecting anything other than massive levels of oil) no monitoring was carried out during an exposure event. Further monitoring studies using Tedlar bags continued throughout 1997 and 1998 with similar findings.

A 1996 study by Dechow for Airbus using A310 and A340 aircraft [120,121] reports concentrations of VOCs and the irritant formaldehyde with most volatiles and particulates emitted by passengers (mainly ethanol and tobacco smoke). The general air quality measurements were only made during routine flights (that is, with no unusual air quality incidents reported [1,2,114]). The report stated that all detected VOCs were found to be in concentrations similar or lower than other indoor spaces and did not influence health and comfort.

A 1996 Allied Signal report collated 77 Ansett cabin air odour reports from one base over an 18-month period. Fumes were reported in 65% of flights with smoke reported in 5% of the flights. [122] Adverse effects (*'sick'*) were reported in 55% of the flights. An investigation was undertaken some time (months after surveys completed) later with an engine removed for suspected oil leakage. Air quality checks were undertaken to look for CO, CO_2, NOx and hydrocarbons. CO was noted at 15 ppm at transient operations during testing. A number one seal leak was found allowing oil into the customer air bleed and the number two bearing package was repaired.

A 1997 study carried out by Lee actually installed a gas chromatograph on a BAe 146 (all other studies collect samples for later laboratory analysis). [123] The analyses reported nothing untoward was detected by the gas chromatograph and none of the crew complained of any unusual smell. Again, this indicates monitoring was conducted in the absence of an exposure event. Using a novel technique, air sampling was also conducted during a pack burn out, by pumping cabin air through a vessel cooled with liquid nitrogen, in an attempt to capture everything in the air sample. Subsequent analysis identified tricresyl phosphate in the sample. The possibility that all other monitoring studies were unable to detect tricresyl phosphate as the chemical is poorly volatile, or eludes sorption onto the sampler, or for some other reason makes virtually all monitoring carried out to date *'highly questionable.'* [66] The final report of this study indicates: on one occasion, tricresyl phosphate was detected at low ppm level in an aircraft cabin during a pack burn. [124] This again suggests that even in the absence of exposure events, low levels of tricresyl phosphates are possible.

Fox of Allied Signal prepared a November 1997 report on air quality measurements on BAe 146 aircraft in service at Ansett Airlines along with an earlier August 1997 interim report. [125] The investigations took place on non-revenue and revenue flights on aircraft with and without new filters. The aircraft had measurable levels of contaminants, which were within an order of magnitude (30-40%) of recommended exposure standards, and above such values (100-130%) in the aft galley. The report stated that this finding applied to contaminants with exposure standards and not to those contaminants that do not have exposure standards – the majority of detected compounds did not have such values, suggesting that the unacceptability of exposure would have been increased even further if all contaminants were considered. Irritating and toxic chemicals included formaldehyde, tetrahydrofuran and cumene. While no tri-orthocresyl phosphate was found, another phosphate ester tributyl phosphate was detected (in minutes from an October 1997 Ansett Australia BAe 146 Odour Committee it was noted that: a full report from Richard Fox would be due in two weeks and that trace quantities of TCP were found in the filters but none in the cabin air: tar looking substances were also found). [126] These findings were absent from final reports from Allied Signal. This report strongly criticised the practice of pack burnouts, suggesting damage to filters (including premature loading of filters with heavier weight hydrocarbons), increased off gassing of contaminants with exposure to levels of hydrocarbons approaching allowable limits continuing for some time after the procedure (formaldehyde was noted to be at a level 30% of its exposure standard). Recommendations for suspension of pack burn outs as an acceptable operational procedure date from this report. A method of assessing filter life was also recommended.

There is some doubt that the monitoring techniques used in this 1997 Ansett Airline/manufacturer investigation [125] (summa canisters) could capture poorly volatile contaminants such as the tricresyl phosphates, and overall, the monitoring in this study was not associated with a definable exposure event. Analysis of air conditioning system filters (the amount of air flow through them was not identified, but likely to be very large) found a significant amount of higher molecular weight residues that could not be identified as well as a number of odour producing compounds not previously identified. It was noted that these higher weight hydrocarbons can generate foul odours or could be the cause of the *'dirty sock'* odours. Despite reporting that the quality of the supply to the aircraft was within safety limits, it was also reported that: bleed air contamination-monitor results indicate other areas of the system are contaminated. Further, in air monitoring for volatile organic vapours, this study notes concentrations were at, or below 3,000 µg/m^3 (3 mg/m^3). This is not a concentration *'orders of magnitude'* below anything that could be considered a problem, but is at the lower level of a *'discomfort range.'* [66,127] While the report noted that the aircraft selected had previously reported odours, again the tests were undertaken during normal conditions and not during any flights where exposure events had occurred. [1,114]

The report noted that exposure standards really do not apply to the aviation environment by stating: [125]

- *'Current safety standards differ from air quality levels that will provide a perceived acceptable level of customer and crew satisfaction. Contaminant levels may be well below recommended levels in currently accepted safety standards - yet generate complaints, because they act in synergy with other contaminants or because some standards may be outdated and not have incorporated more recent scientific and medical evidence. In addition, extenuating circumstances on board aircraft (including humidity and cabin pressure) have not been studied to the extent that a new standard can be proposed - that incorporates these factors or identifies interactions between factors.'*

A follow up report by the same author in 1998 listed many VOCs found in cabin air and noted the major sources of aircraft internal contamination were oil seal leakage from oil seal failure and engine exhaust from combustor component failure. [128] A further follow up (published) report by Fox in 2000 reviewed this earlier 1997 work. [129] Measurements were made of carbon dioxide (4700 ppm in a galley when no dry ice was present), and volatile organic solvents (0.11 to 4.43 mg/m^3). The two 1997 reports (interim and final Ansett report) clearly questioned the validity of using traditional exposure standards and advised these were inappropriate for the aviation setting. This was not, as clearly considered in later 2000 published paper, apart from the suggestion that the only options for exposure standards were ground based standards (ACGIH, NIOSH) or NASA (SMAC) standards developed for astronauts, with the choice left to the study undertaken as '*there was no agreement on appropriate standards (for aircraft) to be used by aviation toxicologists'.* The 2000 published report [129] again stated there was no evidence of any TCP isomers on the charcoal filters used in the air supply system. The report finishes noting that while assessment of aircraft modifications are ongoing, flight attendant perception that there is a problem with the air quality will likely continue with those who show a *'bias against the air quality'*, having had negative experiences. Individuals who perceive that the air is inferior may then become more sensitized to the air, despite the fact that *'individual sensitivities vary from person to person'*.

In 2007, documents relating to the Ansett Australia and Allied Signal testing were tabled in the Australian Senate showing that the information provided by Allied Signal and Ansett about their 1997 testing [125,129] had not been correct. An email sent in September 1997 by Fox to the head medical officer at Ansett (D Lewis) and copied to many others provided data on the *'preliminary trip-report for air quality testing at Ansett.'* [130,131] The email stated:

- '*Tricresyl phosphate is being detected during and after pack burns. Levels measured on the bleed air contamination monitor during pack burn were 4 times greater than we allow for engine acceptance in our APU facilities.'*

This Allied Signal statement is in keeping with the minutes from the Ansett odour inquiry meeting in October 1997, [126] however, it significantly differs from the airline reports and a published paper, which specifically denied this finding. [125,129] Fox advised the author in 2006 that it was the legal company representatives that had ensured the changes were made.

Additionally, an Ansett internal facsimile from Trevor Jensen to Dr Lewis regarding the BAe 146 certification noted that based on the CAA certification requirements [131,132,133] shown in Table 5-4, that the 146 was supposed to meet were as follows:

Page 2 Para 3.2.2	Ventilation	The 146 fails this!
Page 2 Para 3.3.10 (d)	Noxious vapours	Fails
Page 2 Para 3.3.10 (e)	Contamination	Fails

This demonstrates that the engine/APU manufacturer (Allied Signal) was aware that the BAe 146 tested did not meet the regulations as did the airline but continued to state its aircraft met all the rules and regulations. [53] The 1976 British Civil Aviation Airworthiness Requirements [132] (see Table 5-4) replaced by the Joint Aviation Regulation, JAR 25.831 in 1979, show very similar intent to the current airworthiness requirement that the air must be clean.

Table 5-4: British Civil Aviation Airworthiness requirements

British Civil Aviation Airworthiness requirements	
3.2.2	Compartments used by passengers and crew shall be so ventilated that there is adequate air distribution to all parts.
3.3.10	Precautions shall be taken to preclude the contamination of air in occupied compartments resulting from the operation of the aeroplane in normal and emergency conditions. In particular:-
3.3.10 (d)	Systems employing fluids liable to give off noxious or toxic vapours or substances (e.g. some de-icing and hydraulic fluids) shall not be installed-in such a manner as to risk hazardous contamination of the cabin air either by leakage or by use.
3.3.10 (e)	No materials which give off noxious fumes when heated shall be used in such a way that they may become heated in normal or failure conditions to the extent that the cabin air would become dangerously contaminated.

A 1997 air quality survey was conducted by Spengler for Boeing. [134] Air quality measurements were only made during routine flights (that is, with no unusual air quality incidents [1,2,114]), and subsequently, the conclusion drawn was that '*aircraft environments compare favourably to other forms of public transport'.* However, levels of combustion products and solvents were detected despite measurements being taken in the cruise only.

A 1998 report by van Netten on air quality on the BAe 146 carried out air monitoring during non-revenue flights on an aircraft the day after an exposure event. [135] The author notes that the problem in this plane relates to leaks of seals in engine bearings one and nine. The aircraft used Castrol 5000, which was replaced with Exxon 2380 after the incident. Air monitoring used techniques for volatile organic chemicals and *'potential aerosolised oils'*. It is likely that the day after an oil fume event that volatile components or aerosol mists will have dispersed. This proved to be the case. Reports by 112 crew, over a four-month period showed a variety of health symptoms that were considered consistent with exposure to low level CO, Irritants, volatiles, neurotoxins and TCP.

A 1998 Ansett report investigating the oil fume issue on the BAe 146 undertook monitoring samples on 115 flights using Tedlar bag techniques used for monitoring VOCs. [53,136] The final report indicates 57 samples were collected and lists a number of VOCs identified. The high failure rate using this technology was acknowledged by the Flight Attendant Association (which sat on the Ansett committee investigating the fumes) which advised: *'The failure rates of the kits was so high that with hundreds of attempted samplings only 57 successful samples could be analysed.'* [137] Limitations on this technology were also noted by Fox, [125,129] along with the need for different sampling techniques to be used for SVOCs. Despite the limitations, Ansett advised *'all levels measured were less than one-tenth of the maximum levels set for safe exposure. More were less than one-thousandth of the maximum levels set. These levels were set by government regulation.'* [53]

A 1999 report by Haghighat investigated air quality and thermal comfort on 43 commercial flights. Limited measurements were taken only, including temperature, relative humidity and carbon dioxide with a maximum value of 2013 ppm. [138] Again, no measurements were undertaken during non routine or incident events. [1,2]

A 1999 report by Lee investigated air quality on sixteen commercial flights over fourteen months. [139,140,141] Measurements were made of carbon dioxide (a maximum of 2900 ppm), carbon monoxide, ozone and particulates, however VOCs were not measured. No measurements were taken during abnormal incident events, [1,2,114] yet the report concludes that the overall air quality was deemed satisfactory. A health and comfort survey questionnaire was completed by 185 cabin crew, however not at the time of monitoring. Overall the air was deemed to be acceptable despite symptoms of discomfort, irritation, neurobehavioral and gastrointestinal symptoms reported at quite high levels.

A 1999 report by ASHRAE/CSS investigated air quality measurements during routine flights (that is, with no unusual air quality incidents [1,2,114]), in conjunction with a survey questionnaire completed by passengers and cabin crew. [142] Measurements were made of carbon dioxide, carbon monoxide (a mean of 7 ppm), ozone, particulates and volatile organic compounds. In a later review of air quality studies by Nagda, [114] it was determined that *'the least amount of confidence can be placed in the CSS (1998) study because ...the measurement methodology was drawn from industrial hygiene practice, and would be characterized by lower detection limits that could be too high to interpret exposure levels consistent with concerns for the general public. This apparent shortcoming could not be resolved because the publications incompletely addressed data quality considerations.'* It was concluded that there were not significant air quality related health hazards present for either passengers or crew. A consolidation of this project was published in the ASHRAE Journal in 1999, which came to the same conclusion that the air quality was acceptable. [143]

A 2000 report by the Building and Research Establishment (BRE) for British Airways by Ross, conducted cabin air quality in British Airways Boeing 777s. [144] While the report has not been made available for public review, quantitative results for three volatile organic compounds, including aldehydes and ketones were reported elsewhere. [114] Again, none of the measurements were taken during incident events. [1,114]

A 2000 comparison of the environments of transportation vehicles was reported by Dumyahn, including 28 flights on nine aircraft types. [145] Again these were general air quality studies measuring CO_2, CO, and VOCs with concentrations listed as being similar to those found in office buildings and homes. In general, the air quality was reported to pose no health risks although none of the measurements were taken during incident events. [1,2,114]

A 2000 UK airline sample taken from a B737 after a reported fume event was not available for review. [146] The CAA MOR report that referenced this event stated *'An extensive investigation that included the use of an air sample canister was carried out by the operator but no positive conclusions.'* [146]

In 2000, Qantas advised that one of its Southern Australian BAe 146 aircraft with a history of fume events had been monitored for TCP. TCP was positively identified in subsequent cabin air testing at 0.013mg/m^3. [147] The aircraft was stated to meet all the rules with TCP identified below Government levels. While TCP does not have a set exposure standard for the substance as a whole and the use of the TOCP exposure standard had been deemed inappropriate [100,148,149] to be used for the mixture of isomers, this was ignored in the review when suggesting the level of TCP was satisfactory.

A Swedish BAe 146 involved in an incident in which the pilots were incapacitated [150,151,152] was investigated by Fox and Honeywell as well as by the Swedish Defence Research Establishment. [153,154,155,156] The Swedish Accident Investigation Bureau (SHK) reported that the engine manufacturer investigations had found that a carbon seal was leaking oil. The engine was replaced with a subsequent test flight undertaken after a pack burnout. Honeywell undertook testing of the defective engine on the ground in Arizona with a *'minor'* oil leak identified. The results from the ground test [153,154] indicated an increased level of organic substances (that is, oil and fuel) in connection with maximum power application. Subsequent tests showed levels within the specifications/limits set by manufacturer and CAA/FAA. Engineering inspection by Honeywell found that with the exception of the oil leak found by the operator and the minor defects listed below, no fault or abnormality could be found that could have explained a possible discharge of poisonous gases or substances into the bleed air system. Defects found included:

- *Presence of coking on carbon seals for bearing No. 1. Indication of the occurrence of minor oil leak;*
- *Two minor cracks in the oil return line for bearing No. 2;*

- *Presence of coking on carbon seals for bearing No. 2. No indication that any oil leak occurred;*
- *Presence of coking on carbon seals for bearings No. 4 and No. 5. Indication of the occurrence of oil leak;*
- *Presence of coking on carbon seals for bearing No. 9. Indication of the occurrence of oil leak;*
- *Indication of a certain degree of contact ("rubbing") between impeller and impeller housing in the radial compressor.*

The flight test undertaken in Sweden was done without the investigated engine because it had been overhauled and was therefore no longer representative of the occurrence in question. [155,156] The SHK report based on Honeywell's report stated that: *'The results showed that the concentrations of carbon dioxide, carbon monoxide, hydrocarbons, oil degradation products (such as formaldehyde) and ozone were within the stipulated and generally accepted limits respectively. The concentrations of aldehydes, semi-volatile gaseous substances, and volatile organic substances were consistently low. There are no limits established by the FAA or the JAA for these substances.'* The Swedish Defence Research Agency, despite knowing oil leaks had been identified, advised that '*None of the parameters recorded showed results that deviated from generally accepted limits. Some of the TVOC analyses showed, as mentioned, elevated concentrations, but based upon so few measurements, it is not possible to specify a source of the contamination.'*

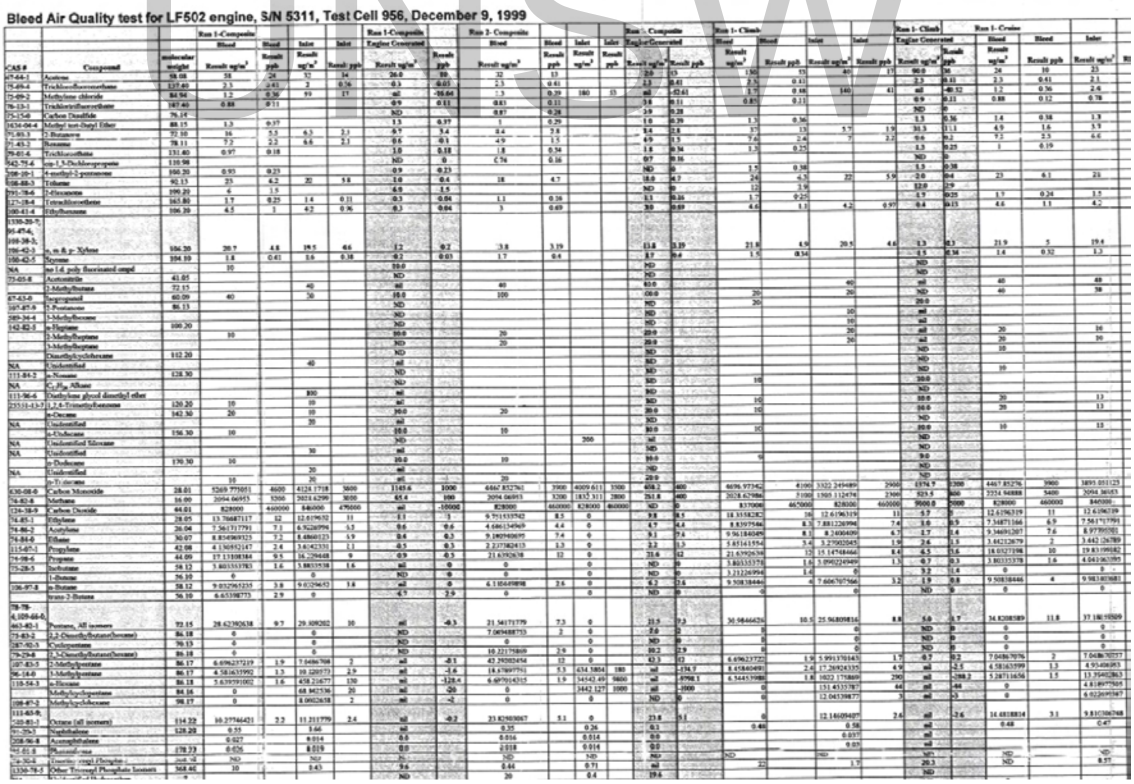
The Swedish SHK advised it: [150]

- *'...can only state that the above mentioned investigations and the air samples that were taken have not led to any clear-cut explanation to what caused this serious incident. The measurement techniques that have been applied and the knowledge that exists within this area have perhaps not been sufficient to reveal the facts. An equally possible alternative is that the contamination that caused the symptoms only appears during very special conditions that did not exist during the engine test cell run or during the aircraft test flight. In spite of this, everything points to the fact that the quality of the cabin air was of crucial* *significance for the incident in question and for other similar incidents that have occurred in other airlines.'*

Given the lack of understanding of contaminated air exposures the SHK advised: *'The incident was caused by the pilots becoming temporarily affected by probably polluted cabin air.'* [150]

However the actual Honeywell reports of the defective engine based upon the tests undertaken in a ground based test cell, [153,154] as shown in Figure 5-2, show that while TOCP was not detected, other TCP isomers (CAS 1330-78-5) were detected in various locations at a reported maximum of 22 μg/m^3. A Hydrocarbon matrix, (*'a broad mix of very heavy tar like co-eluting compounds'* [97]) at a maximum of Max 500 μg/m^3 was reported, as were total unidentified hydrocarbons at a maximum of 80 μg/m^3. Formaldehyde was recorded at a maximum of 45 μg/m^3, while TPP was found at a maximum of 8 μg/m^3 with total PPM contaminants as oil at a maximum of 41.6 ppm and a wide range of VOCs.

Figure 5-2: Bleed air quality test for Swedish incident aircraft



Bleed Air Quality test for LF502 engine, S/N 5311, Test Cell 956, December 9, 1999

The in flight test of the incident aircraft (replaced engine) [155] did not find TOCP, however other TCP isomers (CAS 1330-78-5) were detected at a maximum of 4.9 ug/m^3, TPP (CAS 115-86-8) 20 ug/m^3 maximum, various unidentified (SVOC) hydrocarbons found and formaldehyde reported at a maximum of 58ug/m^3 - (0.047ppm) along with a wide range of VOCs.

The Honeywell reports [153,154,155] do not directly state TCP was found apart from the tabulated charts showing this to be the case. However the report notes that:

- *'Findings indicate that carbon dioxide, carbon monoxide, nitrogen oxides, hydrocarbons (as carbons), oil degradation products (as formaldehyde) and ozone were well below established Civil Aviation Authority (CAA), Federal Aviation Administration (FAA), and contractual limits. Numerous other aldehydes, semi-volatile compounds, and volatile organic compounds were tested for and reported on... No Joint Aviation Administration (JAA), FAA or commercial air transport standards have been established for these comparisons.'*

In this incident, according to the accident investigation report, the contaminated air effects were felt over the previous two sectors and on the third sector, the flight in question, the crew were incapacitated [151,152] (unaware of fumes), the cabin crew and passengers were also affected and no single contaminant was said to be above set standards, despite recognition most contaminants have no such standards. Oil leak defects were found. The reports did not clearly advise TCP and other hydrocarbons were found. The synergistic effect of the mixture of the heated pyrolised contaminants at altitude has not been considered. Although this data comes from the engine manufacturer itself, it is in fact the most complete data available to date on bleed air contamination due to synthetic jet engine oils with subsequent medical effects having been reported in flight and over the long-term. The author is aware, based on the captain's testimony and that of the pilot union, that the pilot in question has subsequently lost his medical certificate to fly.

A 2001, consultants report for ASHRAE by Nagda, [157] also looked at air quality on routine flights on ten sectors on the B737, B767, B747. This is the only study apart from Fox's 1997[114] study to examine air quality in bleed air. Measurements were made of carbon dioxide (a maximum of 4238 ppm), carbon monoxide (a maximum of 9 ppm), ozone and particulates (a maximum of 380 µg/m^3), with SVOCs noted as low under normal operating conditions. The conclusions drawn were that overall bleed air quality was excellent, generally exceeding desired levels of air quality for supply air in other environments. However, the report clearly stated that focus of the research was to measure possible contaminants under normal operating conditions and was not intended to detect or measure contaminants that might occur under *'failure or episodic conditions.'* [114,157]

At some stage around 2001 BAe Systems undertook private research into air quality on its BAe 146 aircraft. [158] While the actual report and data are unavailable for review, it is assumed this is in part the 2001 Marshman work as well as the DSTL/CAA 2001 investigation of the aircraft ducting to determine contaminants that may be present. [93,94,95] An in flight sampling program was undertaken on 68 flights monitoring for a variety of substances (CO, CO_2, RH, temperature, and some flights also measured NO_2, SO_2, formaldehyde and VOCs) with results reported as indicating:

- *'All the flights monitored had acceptably low concentration levels of the measured parameters. Indeed the levels of CO measured never reached detectable levels of the sensor used. During investigation into 'smells' on a BAe 146, it was discovered that the four air conditioning sound attenuating ducts in the rear fuselage were contaminated with a black substance and had a distinct odour. The contamination on the ducts was swabbed and tested, and the results revealed that it contained used engine oil... a negligible amount of hydraulic oil. The engine oil was identified as used Exxon 2380, together with a small amount of Mobil Jet II. The aircraft operator had not used Exxon 2380 since 1997, having replaced it with Mobil Jet II at that time.'* [158]

A 2001 monitoring study undertaken by BRE on behalf of British Airways was undertaken on the B757. However this report remains unavailable for review. All that is known is a summary note in an industry magazine that *'the concentrations of all oil compounds detected in cabin air on the B757 were each less than 100 ppb'*. [159] It is not known how many aircraft were monitored or what contaminants were measured, or whether monitoring was conducted during an exposure event.

A 2002 general air quality air sampling program (no incident events reported), undertaken by NIOSH and CDC and the Civil Aeromedical Institute (CAMI) of the FAA in 2002 found that *'in general contaminant levels measured here were low compared to standards.'* [160] It was noted that there was little research of symptomology amongst aircrew regarding cabin air quality with additional research called for to investigate the relationship between health effects, symptoms and cabin air quality.

Work between 2000 and 2002 by Lindgren and others has measured air quality and studied aircrew perceptions of air quality on aircraft. [161,162,163,164] These were general air quality surveys and did not consider contaminated air. In some cases, cabin crew undertook surveys, however not at the time of flight. However, again this was background monitoring of a few compounds and no monitoring took place during an exposure event. This research also provided evidence on the contribution that smoking made to cabin air quality and was important on banning smoking on flights as a follow on from the original bans.

In 2003 GB Airways undertook limited monitoring in conjunction with BRE and Airbus on an A320 after a fume event had been reported. [165] Questionnaires were completed by crew and Airbus, according to the UK MOR report in which the only data can be found on this monitoring, *'provided analysis of filter contents and confirmed nothing abnormal'.* The airline continued to monitor other flights in conjunction with BRE which found *'results concluded that the surveys carried out showed no unusual results and were typical of other surveys carried out by the team. Air quality levels were within health based standards/guidelines and should not present health risks...'*

A 2003 study of VOCs in different passenger aircraft by the BRE is one of the most complete passenger aircraft VOC investigations currently available. The report includes VOC data from seven flights on BAe 146 aircraft and six flights on Boeing 737-300 aircraft under normal flying conditions. [166] The report states that *'the intention of this study was ...to carry out detailed statistical analysis of the monitored data, not to monitor the air quality during any 'unusual circumstances'.* A report from one of the pilots on one of the test flights states there was a *'lingering smell in the cabin and the flight deck through the flight'* and that *'on arrival the whole team were gloomy and miserable; one male* *member was pale and looked sick.'* Details of this flight appear not to have been included or referenced in the BRE work. [167]

Over fifty different VOCs were identified, although some were at low concentrations. VOC concentrations were normally lowest during the cruise stage of the flight cycle, with the ground, descent and, for a few VOCs, the ascent stages alternating between the highest and second highest concentrations. Total VOC concentrations ranged from 11-1140 µg/m^3, however the total amount of TVOCs appears to be underreported by 11-18% as techniques used to identify TVOCs failed to take into account all quantified VOCs. The maximum carbon dioxide level was 3500 ppm and the maximum carbon monoxide level was 7 ppm. This study notes that one source of VOCs is from passengers, but that another source of a number of specific VOCs was the bleed air system. Semi-volatile organic compounds focussing on those found in engine oils and hydraulic fluids were found to be *'Very low (if any).'* The research did not seek to identify the sources of the VOCs found.

The 2003 EU fifth Framework CabinAir air quality study co-ordinated by BRE from the UK, investigated cabin air and environmental factors on fifty flights with European carriers. [168] A range of parameters were investigated including CO_2, CO, O_3, VOCs, SVOCs (SVOCs (naphthalene) measured momentarily in the cabin air only), and particulates. VOC concentrations were *'comparable to other indoor environments on ground'*. *'None of the measured values of indoor air quality are at levels of concern for health and safety of passengers or crew.'* [168] This again was a general air quality study and was not undertaken using procedures specific to capture oil contaminants [169] Questionnaires were completed by crew listing symptoms and perceptions of the cabin environment. The CabinAir study was a joint EU/industry collaboration with funding undertaken on a cost sharing basis (7.4 million Euros project cost / 3.7 million Euros EU funding [170]) and was utilized as the framework for the 2009 European Standard, BS EN 4618 – *'Aerospace series — Aircraft internal air quality standards, criteria and determination methods'*, [171] prepared by the Aerospace and Defence Industries Association of Europe - Standardization (ASD-STAN). The 4618 standard is *'intended for use in design, manufacturing, maintenance and normal operation of commercial aircraft.'* [171] Additionally the standard *‘specifies requirements and determination methods for newly certificated commercial passenger aircraft programmes’* and *‘may also apply to current production aircraft if it does not carry significant penalties, i.e. if it can be shown to be technically feasible and economically justifiable.’* While formaldehyde, acrolein and CO amongst others were listed as marker compounds for oil or hydraulic leakage, TCP (CAS 1330-78-5) was listed as an identified compound linked to the source (oil, hydraulic leakage) but not as a marker compound with no measurements suggested to be taken. TCP was disregarded for several reasons including: (i) Expected to appear only in very low concentrations, and/or low toxicity for given TLVs, and/or (ii) Below the quantification limit of measurement method. [171]

The CAA undertook a 2001-2004 review of new and used ducting utilized on the BAe 146 as described previously. [94,95] The used ducting was removed from the aircraft some weeks before testing and the possibility that volatile materials present during operation may have evaporated during the intervening period. A wide range of contaminants were found that were reported as a layer of black material consistent with carbonaceous deposits from burned fuels and lubricants and ‘entirely consistent with the pyrolysis products of engine lubricating oil. TCP isomers were reported as *‘far greater in samples of ducting than in samples of unused and used oil which the duct material is acting as a removal and concentration structure for this compound. Thus the duct can remove TCP and other engine oil related compounds, but these compounds are potentially available to re-dissolve in the air stream.’* [94,95]

A 2004 report undertaken by Spicer for Battelle on behalf of ASHRAE sought to relate a potential link between perceived health symptoms, discomfort, aircraft cabin environmental conditions and human factors. [172] Monitoring was undertaken on four flights on two MD-80 aircraft, one B757-200 and one B737-800 with bleed air samples taken for a few minutes during the four flights. Carbon monoxide levels were reported at a maximum of 3.5 ppm, Carbon dioxide at a maximum of 2800 ppm with a long list of VOCs and SVOCs being recorded with no significant conclusions drawn. The project was *‘not intended to address* upset conditions’ and ‘has a limited bleed air quality component’ only [173] and *‘none of the monitored flights included any unusual or episodic events* *that could affect cabin air quality.'* [172] Passengers and cabin crew were asked to complete surveys as part of the research and two of the Battelle scientists and additional participant had oxygen saturation and pulse measurements taken with SpO_2 falling 'to within the range of concern' during the cruise. Part 2 of the Battelle study is currently ongoing and utilized the validated measurement and survey tools to collect data on a statistical sample of aircraft types and routings, and relate the health and comfort survey results from passengers and crew to the air quality and environmental variables observed. [172,174]

In 2005 and 2006, 345 BAe 146 flights were monitored by flight crew in the UK for carbon monoxide. [175] 81% recorded CO readings up to 60 ppm [176] maximum with 39% recording CO readings above 9 ppm. The readings were sea level equivalent figures that did not take into account the effect of altitude, which would have increased the values reported. The detailed log was kept and supplied to the GCAQE, CAA and author. [1]

A 2005 Australian report by Kibby investigated engine bleed air contamination in Australian Defence Force (ADF) military aircraft and noted the presence of tricresyl phosphates (TCP), phenyl-alpha-naphthylamine (PAN) and dioctylphenylamine (DODPA) [177,178] The aircraft tested had a history of smoke and fumes and TCP was detected in all coalescer bags tested. Approximately half of the aircraft tested had quantifiable concentrations of TCPs in the cockpit/cabin air. The maximum concentration of TCP isomers reported was 22 $\mu g/m^3$, with all others below 4 $\mu g/m^3$. The oxidants phenyl-alpha-naphthylamine (PAN) and dioctylphenylamine (DODPA) were recorded at below 0.1 $\mu g/m^3$.

In 2005 a 4 year EU 5th Framework project, HEACE (Health Effects in Aircraft Cabin Environment) run by Oldenburg University in Germany, was completed. The 4.9 million Euro project was made up of a European industry/academic consortium and funded by the EU at 3.3 million Euros. [179] The investigation of environmental impact in the aircraft cabin on performance, well-being and health of cabin – flight crew was the objective. [180] The study utilized two simulators that did not utilize bleed air or pressurization (BRE cabin simulator in the UK and Austrian Airlines flight simulator) and six long haul flights on the A330 and A340. The in flight research measured sound and vibration, temperature, humidity, draft and air quality (CO_2, CO, VOCs and number of germs. At the same time a number of physiological parameters were measured: heart rate and variability, blood pressure, oxygen saturation, salivary cortisol and skin conductance along with questionnaires completed by the crew as well as questionnaires and physiological data recorded during the simulator mock ups by the crew as well as passengers. While people perceived the air quality on the flights became more *'smelly'* as time went on, this was not reported by the air quality parameters measured. Essentially this project did not attempt nor did it review contaminated air, however air quality was listed as one of the parameters measured. Another EU project, FACE (Friendly Aircraft Cabin Environment) running from 2002 to 2007, addresses the environmental comfort parameters affecting noise, vibration and air-quality technology: however, is not considered in this thesis.

A 2006 NIOSH report investigating the BAe 146/RJ in 2003 after a confidential request was received from the airline union, expressed concerns about air quality in the rear of the aircraft and noise. [181] The report states that *'Some chemicals were found in very low concentrations. These were presumed to be from cleaning products, jet fuel, deicing fluid, and engine operations.'* All levels identified were *'consistently below relevant occupational limits'* in *'concentrations that are not considered to pose an increased risk for health effects.'* The sampling and analytical techniques used to detect VOCs in the analyses had not been validated, with all results to be considered as estimates. [181]

A Cabin Air Sampling Functionality Test was carried out as contracted research for the UK Department for Transport by Muir (Cranfield) in 2008. [182] This study tested monitoring technologies in a BAe 146 on the ground in a hangar and a B757 in flight. The methodologies suffer from a number flaws, [183] including monitoring on the ground, sampling for volatiles/semi-volatiles and not mists or particulates, and assuming that workplace exposure standards apply at altitude. The results, such as they were, collected the usual range of volatile organics, indicated that during the BAe 146 tests (held on the ground with no *'bleed air contamination event'*):

- Tributylphosphate was present at all times within the cabin, (up to 20 times higher than background in the hanger at 23–42 µg/m^3) even before switching on the APU. This is a major component of hydraulic fluids and indicates residual contamination;
- Tricresyl phosphate was detected when the APU and ECS (Tests 3 and 4 at 0.6–1.3 µg/m^3) systems were running and fifty times higher than in earlier tests. The ratio of tri-cresyl phosphates to the synthetic esters contained in Jet Oil II found in the aircraft atmosphere is different to the ratio found in the liquid reference material, indicating residual contamination.
- Kerosene range (C_9-C_{15}) compounds and lubrication oil range (C_9-C_{15}) compounds were detected when the APU was switched on (indicating unburned fuel and oil were being taken into the air conditioning system);
- 2,5-Diphenylbenzoquinone was detected when the APU was switched on;
- Mobil Jet oil II found in cabin with APU and ECS running up to seven times higher than background levels (4-11 µg/m^3);

During the B757 tests (held in flight) a qualitatively similar variety of volatile/semi-volatile organic compounds were found as on the BAe 146. Similar levels of tributylphosphate were found as on the BAe 146 (2-8 µg/m^3) and TCP was found at a reported maximum of 0.04 µg/m^3. The concentration of total tri-cresyl phosphate found was noted and *'some of the concentrations of Jet 2 on the first feasibility study (on a BAe146 aircraft on the ground) were higher than this level, though no 'bleed air contamination event' was noted by those present on that occasion.'* Jet II oil found was at a maximum of 5 µg/m^3.

This study identified that two techniques; (i) the pumped thermal desorption technology and (ii) the photoionisation detection (PID) technique were the most appropriate techniques for determining the compounds likely to be present on aircraft with the former being the most appropriate.

Most importantly, during the flight of the B757, a *'fume event'* occurred, noticeable by *'a distinct oily type odour which persisted for less than a minute before dissipating,'* and which formed part of a pumped sample collected over an eighteen minute period. Monitoring indicated that there was a sharp rise in '*ultrafine particles*', higher concentration of Mobil Jet Oil II, and higher levels of tricresyl phosphate. It was noted that *'instantaneous Jet II/Skydrol concentrations could have been around ten times the average value'* listed.

Limited though these results may be, this study did identify the presence of tricresyl phosphate on an airplane associated with a fume event. Further, it indicated that APU operation released a range of compounds into the airplane environment. For the first time, albeit incomplete and non-quantitative, evidence is available that particles (designated as ultrafines), volatiles, and tricresyl phosphate are released during a (in this case, minor) *'fume event.'*

The report states that *'in all instances the detected concentrations from the sampling using thermal desorption tubes were significantly below the relevant HSE specified WEL where applicable. It should also be noted that wherever possible, WELs are set at a level at which there is no evidence of adverse effects on human health.'* The external reviewers including US FAA Airliner Cabin Environment Research (ACER) researchers, noted strong concerns on some of the techniques used (Photoionization detectors, (PID); Thermal Desorbtion, (TD); Solid Phase Microextract Fibres (SPME)) and noted that particle/aerosol counting (that had not been undertaken) should be considered for future work. The Cranfield report questioned (incorrectly) why the ACER researchers felt the *'only compounds of interest are tricresyl phosphates.'* [182]

A small research study undertaken by van Netten in 2008 investigated the use of a small air sampling system using standard air filter sampling technology to monitor the air in aircraft. *'A set of samples taken by a BAe-146-300 crew member during two flights in the same aircraft and analyzed by GC-MS, indicated exposure to tricresyl phosphate (TCP) levels ranging from 31 to 83 nanograms/m^3 (detection limit below 4.5 nanograms/m^3). The latter elevated level was associated with the use of the auxiliary power unit (APU) in the aircraft. It was concluded that the air sampler was capable of monitoring air concentrations of TCP isomers in aircraft above 4.5 nanogram/m^3.'* Correction for altitude led to the TCP levels of 36, and 108, ng/m^3 reported at altitude. [184] One crew member reported *'a mild headache that persisted for five days'*, while another smelt a '*light smell/odour*' associated with the elevated sample taken with the APU running. Importantly the TCP results were said to *'likely reflect background levels and not upset conditions such as fume events in the cabin.'* [184]

The European Ideal Cabin Environment (ICE) project, also led by BRE from the UK, was undertaken by a European consortium under the EU 6th framework FP6 program ongoing over 3.5 years to late 2008, costing 5.9 million Euros with in excess of 4 million Euro EU participation. [185] The project was based on the 2003 EU CabinAir project with new parameters investigated and the combined effects. The aim of the project was to establish target levels and ranges of cabin environment parameters, specifically pressure, airflow, humidity and temperature both individually and in combination *'to ensure that the cabin provides a healthy environment (both physiological and psychological well-being) for passengers in commercial aircraft.'* Tests were undertaken using ground based simulators (BRE ACE simulator and FTF Fraunhofer facility) that did not use bleed air. Cabin air contamination was not addressed at all. A variety of physiological tests were undertaken along with survey questionnaires to assess the interactions of the parameters. However, the conclusions included the statement that *'flying in current commercial aircraft environments poses no significant health risk for passengers.'* This finding has been widely quoted indicating that cabin air is suitable for the travelling public.

The ICE project is being developed by the European ASD-STAN into a European Pre Standard 4666 known as the *'Aircraft integrated air quality and pressure standards, criteria and determination method*s.' [186] The standard is being prepared by the ICE working group with the lead co-ordinator being BRE from the UK. Pr En 4666 is complementary to EN 4618, but addresses the additional requirements of cabin pressure. [185,187] It utilizes all the chemical limits defined under *'air quality'* in the 4618 standard, [168] including formaldehyde and CO, but fails to utilize TCP as a marker compound. The current cabin air standard *'covers indoor air quality and thermal comfort',* while the new cabin air standard (4666) combines effects. [187] However, the failure to utilize contaminated air research, bleed air and known bleed air contaminants such as TCP, as the basis of *'air quality'* studies and EU standards (4618 and 4666) was highlighted as problematic directly with ASD-STAN. [188] This is supported by a statement from BRE acknowledging that *'Earle Perrera stated that any contaminated air issues were not part of the study towards prEN4666 and that the equipment used was not designed for such purpose.* [188]

'In-flight Measurements of Cabin Air Quality' are currently ongoing in a joint Harvard School of Public Health (FAA-funded) Battelle Laboratories (ASHRAE-funded). [174] *'The objective of the project is to understand the relationships among environmental conditions of the cabin (as well as other factors) and the perceptions of health and comfort of passenger and crew members.'* The *'anticipated Outcome'* is the *'assessment of overall cabin air quality of aircraft during normal operation.'* Preliminary data was collected onboard Singapore Airlines during 2008 and 39 Southwest Airlines flights in 2009. The in-flight sampling consisted of collecting continuous environmental measurements of ozone, carbon dioxide, carbon monoxide, particulate matter, temperature, relative humidity, pressure and sound level. Integrated samples were collected for volatile organic compounds (VOCs), carbonyls and semi-VOCs. Passenger and crew comfort surveys were distributed during one third of the flights. Analyses of the data are continuing. As this research has not been completed, it has not been included in the surveyed data in Table 5-3.

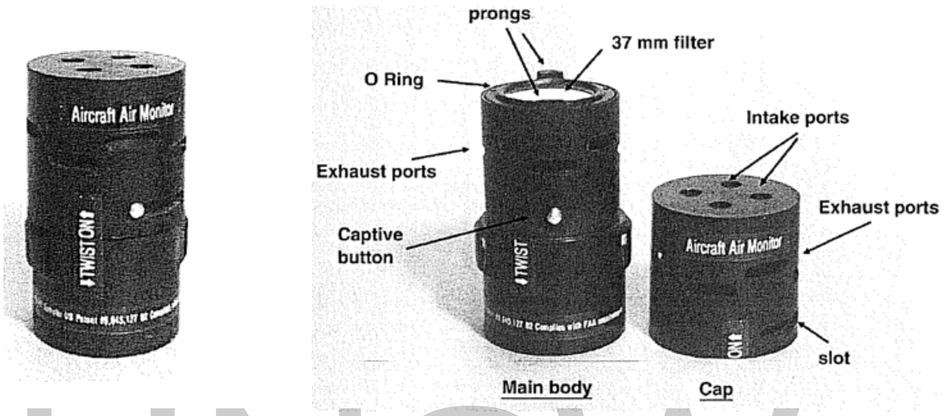
In 2008 the US FAA funded ACER/OHRCA research project identified TCP in 10 out of 55 (18%) air monitoring samples. [189] 'Very low levels of TCPs were detected under normal operating conditions,' with 'the TCP isomeric pattern of the chromatographic fingerprint suggest(ing) engine oil as the source. This was detected under normal operating conditions, where some oil leakage may occur', with 'background levels of TCP isomers …anticipated in aircraft in general.' The intent of the project was 'to establish a relationship between airplane cabin air exposure and potential adverse health outcomes' with monitoring to be undertaken at the same time as the surveys were collected pre and post flight. However, monitoring by cabin crew was not allowed by the airlines using a recently developed sampler (the VN sampler; see Figure 5-3) and had to be undertaken by researchers and the airlines refused permission for the cabin crew to undertake the surveys associated with the monitored flights. [189] As such, the cabin crew health survey was undertaken as a separate project and had nothing to do with air quality.

TNO in the Netherlands analysed ten cabin air samples for TCP taken from the Fokker F70, F100 and B777 aircraft. Six out of ten were positive for TCP (maximum, 43 ng/m^3, with TBP recorded in all samples (maximum 1475 ng/m^3). [190]

A number of TCP swab tests have been undertaken since 2005.

Figure 5-3: The VN Sampler

From van Netten [184]



The assembled sampler **Details of unassembled sampler**

A 2005 report by van Netten undertook GC-MS analysis of swab samples taken from B757 flight deck filters, B757 precirculation filters, B757 HEPA filters (930 μg TCP/filter, total area 4.5m^2), B757 forward lavatory ceiling filters and found TCP in all samples analysed. [176] Swab samples taken from BAe 146 flight deck walls near the side vent and on a BAe 146 pilot's trousers also identified TCP (0.17 μg/pair of trousers). Six out of seven samples tested positive for TCP with TPP also identified.

Van Netten analysed seven swab samples for TCP from B757 aircraft avionics roof top filters and wall swabs using GC/MS analysis. [191] All seven swabs were positive for TCP. The report stated:

- *'The presence of TCP isomers on the filter elements as well as the wipe samples do clearly indicate that flight crew members are exposed to these isomers in their work environment. TCP will also just be one of numerous chemicals crews will be exposed to during exposure to contaminated air. These chemicals will most likely act in synergy.'*

The Norwegian Institute of Occupational Health analysed three BAe 146 swab samples for TCP using GC–MS. [192] TCP was found on all wipes (TmCP in all samples, and TpCP in one sample) in the mass range 0.03-0.18 µg (total mass on wipe). In addition, triphenyl phosphate (TPP) was determined in all samples in the concentration range 0.14-1.8 µg, while tributylphosphate was determined on two wipes (0.25 and 0.45 µg). No fume event was recorded.

A number of swab samples were undertaken by crew on a variety of aircraft in Australia, USA, UK and Europe including B777; B737-400/700; B757; B747-400; MD80; A330; BAe 146/146/RJ; Dash8-100/400; F70/100; A319. All samples were analysed by Van Netten with 31 out of 40 testing positive for TCP, including the meta, para and ortho isomers. [193] The maximum reading reported was 18 µg/wipe.

German based WDR undertook swab sampling on a variety of German registered aircraft in 2009. These were analysed by Van Netten, [194] and 29 out of 31 samples were positive for TCP with the highest recordings for a B757 taken at two differing times within a short period at 64,976 and 154,950 ng per wipe sample.

A number of other studies were undertaken that related to general air quality rather than contaminated air investigations. [195,196,197,198] Other studies were undertaken involving survey questionnaires only. [199] The FAA OHRCA/ACER research [189] set out with the intention of correlating health symptoms reported by flight attendants during air monitoring under routine or upset conditions, however the survey questionnaire was not able to be undertaken as a part of the monitoring study. Instead a baseline survey was completed by over 4,000 flight attendants, collecting data on work conditions, symptoms and diagnosis, however it did not relate to air quality or monitoring.

5.3.2.1 TCP identification

The antiwear phosphate additive TCP, used in synthetic jet engine oils at 1-5% (most commonly 3%) has been found in a number of studies as shown above. Table 5-5 provides a summary chart of where TCP has been found.

While TCP is not the only focus of exposure to contaminated air in aircraft, it is an important substance to investigate, as it is the main engine oil additive and is toxic. It has been suggested that to look for TCP specifically would indicate this is the only compound of interest [182] and that all compounds should be monitored for without focussing on a single compound. [4]

Table 5-5: TCP identification in aircraft

Year	Source	Reference	Aircraft	Location of TCP	Max Quantity	Oil source
1988	Kelso, ADF	107	C-130	Filter bags in ducting		Yes
1997	Fox, Ansett	129, 130, 131	BAe 146	Filters	4 times Allied Signal standard level	Yes
1997	Lee, Ansett	123, 124	BAe 146	Cabin air	Low ppm	Yes
1998	Qantaslink	147	BAe 146	Cabin air	0.013 mg/m^3	Yes
1999	Honeywell	153, 154, 155	BAe 146	Cabin and bleed air	4.9 µg/m^3 22 µg/m^3	Yes
2004	CAA, DSTL, BAe	94, 95, 158	BAe 146	Ducting	1 µg/g ortho isomer 68.1 µg/g meta isomer 8.1 µg/g para isomer	Yes
2005	RAAF	177,178	Military	Cabin air	22 µg/m^3	Yes
2005	van Netten	176	B757 BAe 146	Swabs 6 out of 7	Up to 930 µg/wipe	Yes
2006	van Netten	191	B757	Swabs 6 out of 6		Yes
2006	NIOH	192	BAe 146	Swabs 3 out of 3	0.18 µg/wipe	
2008	Muir	182	B757 BAe 146	Cabin air	1.3 µg/m^3	Yes
2008	van Netten	184	BAe 146	Cabin air	36 to 108 ng/m^3	Yes
2009	GCAQE	193	Various	Swabs 31 out of 40	18 µg/wipe	Yes
2009	TNO	190	F70, F100, B777	Cabin air 6 out of 10	43 ng/m^3	
2008	OHRCA	189	Variety	Cabin air	17 out of 56	Yes
2009	WDR	194	Variety	Swabs 29 of 31	Up to154,950 ng/wipe	Yes

However TCP is a specific chemical with known use in jet engine lubricating oils, is quite unique with TCP levels at around 3% and one without many other uses in industry today. Additionally there is wide acceptance that oil leaks are occurring and are a feature of the design of bleed air systems. Additionally it was suggested in 2007 that TCP had only been recorded in 1 military study, [4] which clearly is incorrect.

TCP has been recorded in at least 16 studies including military and civilian aircraft studies since 1988. These studies include TCP being found in cabin air, bleed air, filters, aircraft ducting and swab sampling of filters (flight deck, HEPA filters and interior cabin walls). Oil was specifically identified as the source in 14 out of 16 of these studies. 75 out of 87 (86%) swab samples for TCP have positively identified TCP with some specifically showing the meta, para and ortho TCP isomers. Therefore exposure to TCP in the passenger cabin is occurring [184,191] and the isomers can be accurately identified to correspond with the TCP isomers used in jet engine oils. [102,103]

TCP has additionally been found in the blood of several pilots (blood cell membrane, NIOSH method) after contaminated air events, [200,201,202,203] in crew urine tests and on a pilot's trousers. [176]

5.3.2.2 Air quality studies/epidemiological review

As many in the aviation industry suggest that cabin air is acceptable, others suggest that while no accurate measurements related to epidemiological data are available, no link can be drawn to suggest cabin air can be unhealthful. [2,3,4] Therefore the data that are available on cabin air quality must be reviewed to determine if it is possible to suggest cabin air is safe and healthful. Secondly it is necessary to determine if it is suitable to suggest that the only way to draw a link between contaminated air events and adverse health is through a full-scale epidemiological survey undertaken with a major air monitoring study or whether there are currently suitable data to indicate cabin air can be unhealthful.

Table 5-6 provides an analysis of the studies known to have been undertaken to date.

To date, a total of 55 cabin air quality studies have been undertaken within the airline industry. There may well be more, however for commercial reasons data is not always made publicly available or the reports were not available in the

English language. Of these studies, 53 included air monitoring, while one military study involved maintenance findings.

33 studies involved specific air quality monitoring for contaminated air, while 20 (38%) assessed general air quality and did not aim to assess air quality during contaminated air events.

Table 5-6: Breakdown of cabin air quality studies

Study	Number
Cabin air quality studies.	55
Air quality monitoring.	53
General air quality monitoring.	20
Contaminated air specific air quality monitoring.	33
No monitoring.	2
Monitoring undertaken during fume event - (*1 B757 sector only – minor event).	1*
Monitoring not undertaken during fume event.	52
Epidemiological monitoring.	13
Specific monitoring/not during contaminated air event/epidemiological during monitoring.	0
Specific monitoring/not during contaminated air event/epidemiological not during monitoring.	5
General air quality monitoring/epidemiological during monitoring/not during contaminated air event	6
General air quality monitoring/epidemiological not during monitoring/not during contaminated air event	2
Investigation/no monitoring/epidemiological.	1
No monitoring/epidemiological.	1
TCP found.	16
Oil constituents identified as source.	21
Cabin air acceptable/general air quality monitoring.	12
Cabin air acceptable/specific air quality monitoring.	9
Cabin air quality acceptable	21

52 of the 53 (98%) air monitoring studies did not take place during the contaminated air events. The one study that undertook any air monitoring during a fume event was the Muir/Cranfield 2008 study. [182] Of the four B757 flights undertaken in this study, one flight was associated with an identified but minor fume event. TCP and jet engine oil were identified to rise during this event, however the findings were still lower than for the BAe 146 studies on the ground with no fume event. This indicates that identification of a fume event

(generally through detection using the human nose) is not the overriding factor and aircraft not reporting a fume event aircraft can experience contaminated air.

While epidemiological data collated were sparse and only collated in 13 studies, it varied from telephone follow up, to review of medical records, collation of symptoms or in a few cases only limited physiological monitoring during flight. Table 5-3 provides details of the type of study undertaken and type of flights involved.

No studies involved specific monitoring for contaminated air (no fume event) with epidemiological evaluation studies undertaken at the time. Five specific contaminated air studies undertook air quality monitoring (not during fume event) with epidemiological data taken at a later time. These studies included telephone interviews and a review of limited medical/illness records; collation of adverse effects and odours and questionnaires. [108,115,122,135,165] Three of these suggested the air quality was acceptable. [108,115,165] Two were airline studies with one undertaken by NIOSH. None involved any physiological testing.

Eight studies for general air quality were undertaken with some form of epidemiological study. Six involved epidemiological data (in conjunction with air monitoring) ranging from surveys completed by passengers and crew, [142,168,172] to limited medical assessment and limited physiological testing in three studies. [185,197,198,180] At least one of these specifically, was a major EU study that did not use techniques suitable for monitoring contaminated air events. [168,169] Another study did not even involve the use of bleed air, [185] while another looked at three VOCs only and no SVOCs as it was assessing perception of cabin air quality and humidity. [197,198] Two of the studies involved collating all or most of the survey data separately from the air monitoring. [141,162]

Sixteen studies identified TCP in the aircraft or bleed air, while 21 studies identified oil contamination as the source or part of the source of the identified compounds. All were studies specifically looking at contaminated air.

Cabin air quality was specifically deemed acceptable or within limits by twelve general air quality studies. These include: Nagda/1992; CCS/1994;

Spengler/1997; Dechow/1997; Lee/1999; ASHRAE/1999; Dumyahn/2000; Nagda/2000; Waters/2000; BRE/2003; EUCabinAir/2003 and ICE/2008. Of these, only ICE, EU CabinAir, and the 1999 ASHRAE project (Lee on one air monitoring flight) undertook any form of crew/passenger evaluation, while none of the twelve studies used specific methods to detect bleed air contamination or undertook monitoring during a fume event. One did not even test bleed air and was not looking at contaminated air as a parameter, however it stated *'air quality was acceptable'*. A close review of a number of these studies indicates industry/Government ties, such as: Industry funded (CCS), Boeing funded (Spengler, Dumyahn) Airbus funded (Dechow); Airline funded (Lee); Government funded (Nagda 92, Waters, BRE); Government and Industry consortium (EU Cabin Air & ICE); ASHRAE/Boeing funded (CCS 99, Nagda 2001).

Cabin air was specifically deemed acceptable in nine studies that specifically suggested they were monitoring for contaminated air. These included: Alaska Airlines/1990; Domnick Hunter/1992 (BAe Systems); NIOSH (Alaska Airlines)/1993; Currie (Ansett)/1995; Fox (Ansett)/1997; Sleigh (Ansett)/1997; Qantas/1998; GB Airways/2033 and NIOSH (Mesaba Airlines)/2006. Of these only Alaska Airlines, NIOSH (1993) and GB Airways undertook any form of crew evaluation, specifically telephone consultations, medical and illness records review and questionnaires only in the later case. None of these took place during a contaminated air event. Of the nine stating air was acceptable, a strong industry affiliation was shown: Manufacturer × 1; airline × 5; OHS regulator × 2; airline and manufacturer × 1.

The following points can be therefore made:

- 38% of air quality monitoring studies did not undertake monitoring for contaminated air substances, while 62% did;
- No air monitoring during a contaminated air event occurred except for one brief fume event in part of an air quality investigation with the levels recorded (averaged over a long time period) being less than another aircraft type on the ground that did not identify any fume event. Both aircraft types investigated identified TCP and jet oil contamination amongst other substances;

- Epidemiological data of any form was taken in only 25% (13) of the monitoring studies and this was of very limited value. Two other studies that did not undertake air monitoring collated limited epidemiological data;
- No epidemiological study was undertaken at the same time as the specific contaminated air studies. Five specific contaminated air studies undertook limited human studies of varying forms separate from the monitoring and were of limited value. Three suggested the air quality was acceptable and could not cause adverse effects;
- 60% of the general air quality studies deemed the air acceptable (12/20). All twelve studies (see above) had industry or government funding including manufacturer or airline studies or funding;
- 27% (9/33) of the specific contaminated air studies suggested the air was acceptable. These showed a strong industry affiliation;
- Far greater likelihood of aircraft air acceptability was shown by studies that did not review contaminated (specific air quality events) air, yet few differentiated clearly or at all that the studies only applied to normal operating conditions.
- TCP was identified in 48% (16/33) of contaminated air specific studies, none of the general studies and in 30% (16/53) of all air quality monitoring (specific and general) studies.
- Oil was identified as the source or part of the problem in 60% (21/33) of specific contaminated air studies undertaking monitoring and none of the general air quality studies;
- One airline/manufacturer study published that air quality was within limits and no TCP was found, [129] when this was not the case and contaminated air had been identified above manufacturer limits with TCP identified. [130,131]

This highlights that general air monitoring studies have been widely used to suggest the acceptability of cabin air for the health and safety of aircrew and passengers, despite that the studies did not intend nor did they appropriately review contaminated air issues. The specific cabin air studies were in some cases of limited value, while some other more extensive studies revealed significant findings based on review of the actual data. However, these studies would report a satisfactory outcome. Only one flight reported a minor fume event at the time of testing and this was recorded at levels lower than another aircraft on the ground monitoring background levels. The epidemiological studies of the specific contaminated air studies were of very limited value, were not undertaken at the time of monitoring and cannot provide virtually any information on the adverse effects of contaminated air.

5.3.2.3 Air quality reviews

A summary of air quality reviews is shown in Table 5-7.

Table 5-7: Air quality reviews

Reference first author	Year	Comment	Conclusion
NRC [204]	1986	Inquiry into the airline cabin environment	Oil seal leaks can allow oil to leak into the bleed air as a vapour or mist; source of VOCs.
Rayman [117]	1997	Review of a number of air quality studies.	Very low levels of contaminants in airline cabins. Too low to cause adverse health effects. Other factors more likely to be the problem.
Thibeault [206]	1997	Aerospace Medical Assoc position statement on aspects of cabin air	Contaminants identified in various studies are within limits. Other multifactorial factors are thought to be the problem.
Hocking [207,208, 209]	2000	Review of air quality supplied to aircraft over 25 years.	Significant decrease in amount of outside air supplied to cabin with variety of adverse implications.
Nagda [118]	2000	Review of cabin air quality studies between 1985-1998.	CO_2 levels found may be inadequate for aircraft environment. Paucity of data or inadequacies in methods and instrumentation used for measuring preclude definitive conclusions.
Space [210,211]	2000	Review of current information on aircraft environment and other factors that affect comfort.	Multiple factors are likely responsible for perception of aircraft environment.
Australian Senate [27]	2000	Inquiry into air quality on the BAe 146.	Aviation safety regulator not enforcing its own legislation; Cabin contamination occurred; Under reporting of leaks was a problem; Ill health related to exposures likely.
NRC [2]	2001	Inquiry into the airline cabin environment and the	Oils contain toxic ingredients that may affect air quality during abnormal flying conditions.

Reference first author	Year	Comment	Conclusion
		Health of Passengers and Crew	
UK DETR [205]	2001	Consultation exercise to identify issues of concern about possible harmful aspects of the aircraft cabin environment.	Current knowledge on physical and chemical aspects of aircraft cabin air quality cannot completely resolve a number of concerns such as the potential contamination of aircraft cabin air with lubrication oils.
UK DETR BRE [214]	2001	Literature review investigating effects on health of aircraft cabin environments including exposure to OPs	OPs are chemicals of high toxicity and can enter cabin air when oil leaks occur; *'little substantial evidence to support the perceived risk.'* Monitoring of normal cabin air and OPs and effects of multiple chemical exposures and interaction with other cabin conditions required.
EU Parliament [215]	2001	Report cabin air environment and health impacts.	Some concern that high levels of VOCs from engines can enter the cabin, however no problem under normal operating conditions.
Rayman [3]	2002	Review of aspects related to cabin air quality.	Previous studies conclude that levels of contaminants found in airline cabins *'are very low and, therefore, unlikely to cause adverse health effects.'* Evidence is not conclusive. However for various reasons; Other factors may be the real cause.
Nagda [114]	2003	Review and assessment of aircraft cabin air quality studies.	None of the monitored flights included any unusual or episodic events that could affect cabin air quality. Under routine aircraft operations, contaminant levels in aircraft cabins are (generally) similar to those in residential and office buildings.
Spengler [216]	2003	Review of aircraft air quality.	Further investigation of toxic exposures from degradation products from lubricants, hydraulic fluids is required as well as other areas of the cabin environment. Chronic lower level exposures to TCP and TBP esters are possible… Potential for neuro toxicological hazard due to the complex mixture of cholinesterase inhibitors in the possible presence of pyrethroids.
AAIB [158]	2004	Incident investigation of a variety of contaminated air event flights.	Very little data available on potential contaminants and analysis data on aircraft contaminated air events.
House of Lords [217]	2007	General review of air travel and health	Link between air travel and health still not proven.
Committee of Toxicity [4]	2007	Review of Cabin Air Environment.	Not possible to link ill health and exposures, however association between acute health effects and exposures is plausible.
TNO [220]	2007	Monitoring technologies for aircraft cabin air.	Current knowledge of aircraft air quality and is limited. Technology review to identify appropriate or novel technologies to identify and quantify cabin air.

Reference first author	Year	Comment	Conclusion
ASHRAE [10]	2007	Air quality standard	Standard defines the requirements for air quality in air-carrier aircraft and specifies methods for measurement and testing includes comprehensive bleed air contamination section
CASA EPAAQ [222]	2008 Cont.	Expert panel established to review potential health effects of exposure to contaminated cabin air	Ongoing
EASA A-NPA [223]	2009 Cont.	A-NPA - Cabin Air Quality onboard Large Aeroplanes.	Ongoing

The first general review on aviation air quality was the 1986 report of a committee of the National Research Council (NRC), the principle operating arm of the US National Academy of Sciences and the National Academy of Engineering. The report produced was entitled 'The Airliner Cabin Environment: Air Quality and Safety'. [204] This report noted, among other things, that the NRC *'attempted, but abandoned, the separation of issues of health from those of safety'*. The report also recommended minimum standards for a range of air quality issues, including ventilation rates, carbon dioxide, ozone, tobacco smoke (it suggested prohibition of smoking on flights) and aerosols. The report acknowledged oil seal leaks can allow oil to leak into the bleed air as a vapour or mist and be a source of VOCs. However, the report was unable to assess the potential health hazards to passengers or crew from other contaminants, such as volatile organic compounds.

In 1997, the current Executive Director of the Aerospace Medical Association (ASMA) reviewed a number of air quality studies. [117] Based on the 1989/1992 and 1994 CCS study as well as others, he determined that '*levels of contaminants in airline cabins are very low and therefore not likely to cause adverse health effects... Both generations of aircraft easily meet the requirements for maintaining a healthy, quality environment. Lowered barometric pressure, lowered ambient oxygen pressure, vibration, low humidity, noise, fatigue and jet lag are probably the cause of symptoms.'* Another study undertaken by ASMa in the same year found that contaminants identified in various studies were within limits. [206] *'The so-called problem of cabin air quality is most likely multifactorial (hypoxia, decreased barometric pressure, crowding, inactivity, temperature control, jet lag, noise, three-dimensional motion, fear, stress, individual health, alcohol consumption, etc.).'*

A further 2002 report by Rayman (AsMa) [3] noted that previous studies conclude that levels of contaminants found in airline cabins *'are very low and, therefore, unlikely to cause adverse health effects.'* However, it was noted that *'the evidence is not conclusive and for various reasons including lowered pressure, hypoxia, low humidity, noise, jetlag, crowding, circadian dysnchrony, work/rest cycles, vibration, turbulence, anxiety fatigue caused by airport tumult, pre flight anxiety, long distances to departure gates and confusing directions etc... These may be the real culprits rather than air quality?'* The review reported that as long as the aircraft systems are functioning normally, the evidence supports that cabin air quality is healthy and satisfactory. However in the cases of systems failures (such as a ruptured line or electrical fire) fumes, smoke and toxic substances can be released into the cabin air. Additionally it is reported that there is no evidence in the literature linking cabin air quality with epidemiological studies of crew or passenger illness. *'It would be necessary to monitor cabin air quality and conduct parallel health surveillance of crew/passengers for illness to determine if there is a reasonable temporal relationship of contaminants in the aircraft cabin with adverse health effects.'*

Additional studies have been undertaken reviewing aspects of aircraft air quality including the work by Hocking. [207,208,209]

In 2000 Nagda [118] reported on various air quality studies that 'CO_2 *levels found may be inadequate for the aircraft environment. Paucity of data or inadequacies in methods and instrumentation used for measuring formaldehyde, VOCs,* O_3 *preclude definitive conclusions and SVOCs have generally not been monitored.'*

A Boeing report found that *'The symptoms experienced by flight attendants, such as fatigue, headaches, tiredness, nausea and illness, often attributed to cabin air quality, are more likely due to an interaction of factors that include cabin altitude, flight duration, jet lag, turbulence, noise, work levels, dehydration,* *an individual's health and stress.'* [210] Another Boeing report described in a similar manner, stating multiple factors (cabin environment, individual and job related factors) were likely responsible for perception of the aircraft environment. [211] The paper supported the Rayman (AsMA) findings made in 1997 above.

In 1999-2000, an Australian Senate Inquiry reviewed specifically the contaminated air issue. [27] The report found that the aviation safety regulator (CASA) was not enforcing its own legislation; cabin contamination occurred on the BAe 146 as well as other aircraft types; under reporting of leaks was a problem and ill health related to exposures was likely. The report stated that while in the past many cases of evidence showing threshold exposure levels to chemicals had been found to be safe, experience has now shown this to be incorrect:

- *'Long-term exposure to a number of substances has been shown to be harmful.'* Additionally the panel called for the inclusion of *'aerotoxic syndrome in appropriate codes as a matter of reference for future Workers Compensation and other insurance cases.'*

The UK House of Lords concluded differently than the year long Australian Senate investigation. After listening to a few days of oral evidence and undertaking a very brief review of cabin air within a wider context of air travel and health issues, [212] it concluded that *'under normal operating conditions, volatile organic compounds in cabin air were found to be either undetectable or at very low levels of up to 3 parts per million (ppm).'* The House of Lords also concluded *'that cabin atmosphere levels of volatile organic compounds present no risk to cabin occupants under normal operating conditions.'* This was based on studies drawn to the committee's attention by Boeing, Airbus and others. The report dismissed TOCP exposure as a concern as oil leakage and TOCP exposure would be minimal based on *'calculations by Airbus Industries'* in a worst-case leakage exposure scenario. It also found that there were no significant risks to passengers and crew as there were no cases of clinical TOCP poisoning from cabin air. This was based largely upon evidence stating that there were no formal records (CASe data) being kept at the London National Poisons Information Centre of aircrew TOCP poisoning cases and no such cases in the literature, [213] and was widely quoted for many years as follows: [212]

- *'1.72 The absence of confirmed cases of tri-ortho-cresyl phosphate (TOCP) poisoning from cabin air and the very low levels of TOCP that would be found in even in the highly unlikely worst case of contamination from oil leaking into the air supply lead us to conclude that the concerns about significant risk to the health of airline passengers and crew are not substantiated. (Paragraph 4.41)'*

A further US NRC report was undertaken in 2001 finding that *'the engine lubricating oils and hydraulic fluids used in commercial aircraft are composed of a variety of organic constituents, including tricresyl phosphate, a known neurotoxicant. If the oils and fluids and their potential degradation products (e.g., CO and formaldehyde) enter the aircraft cabin, they will adversely affect cabin air quality.'* [2] The committee recommended that wipe samples of aircraft cabin, cockpit and ventilation ducts as well as filters should be taken and analysed after air quality incidents. It also noted that no published studies to date had undertaken measurements during non-routine air quality events.

In 2001 the UK Department of the Environment, Transport and Regions commissioned a review by way of a consultation process into the possible effects on health, comfort and safety of the cabin environment. [205] This was a broad ranging program which identified a number of issues including that current knowledge on physical and chemical aspects of aircraft cabin air quality cannot completely resolve a number of concerns including the potential contamination of aircraft cabin air with lubrication oils.

A further second section of the UK Government review involved a study undertaken by the UK BRE group, also in 2001. [214] A literature review was undertaken on a broad range of areas including cabin air quality, common pollutants and organophosphates. The review found that organophosphates are *'chemicals of high toxicity, capable of producing serious adverse neurological and other effects',* however in normal operations the risk of exposure to OPs in aircraft cabins is *'minimal.'* It was recognized that there is *'strong'* concern of low level exposure due to oil or lubricant leaks which could cause both short-term and long-term health risks, however there was *'little substantial evidence* *to support the perceived risk.'* The need for normal cabin air quality parameters to be measured should be followed by physiological and subjective responses of people in simulated cabin conditions to combinations of environmental, chemical and physical parameters. Additionally, the need to investigate exposure to OPs in cabin air, and the additivity or otherwise of effects of multiple chemical exposure and the interactions with other cabin conditions was called for. The reports suggested that *'it would be advantageous to have a portable kit that the crew could use to sample the air when fuel or other odours are noticed.'* [214]

In 2001, the European Parliament produced a report on the cabin environment and health. [215] It quoted from the House of Lords report and noted high levels of VOCs from engines can enter the cabin, however, there would be no problem under normal operating conditions.

A further Nagda review paper (supported by Boeing) in 2003 found that *'none of the monitored flights included any unusual or episodic events that could affect cabin air quality'* [114] and that *'Under routine aircraft operations, contaminant levels in aircraft cabins are (generally) similar to those in residential and office buildings.'*

In 2003, Spengler reported that further investigation of toxic exposures from degradation products from lubricants and hydraulic fluids was required as well as other areas of the cabin environment. [216] Chronic lower level exposures to TCP and TBP esters are possible and there was the potential for a neurotoxicological hazard due to the complex mixture of cholinesterase inhibitors in the possible presence of pyrethroids.

In 2004, the AAIB reported in a major BAe 146 incident report that *'It became apparent during the investigation that there was a definite lack of information available on the potential contaminants from lubricating oil, and their associated physiological effects'*, and this was determined to be wholly or in part due to the following: [158]

- No comprehensive airborne analytical test programme had thus far been conducted on a particular aircraft, which suffered from such an oil *'fumes'* incident, where the aircraft remained in the same state as it was when the incident occurred. For example, with the subject (defective seal) engine still installed and with the same type of oil as was being used at the time of the incident;

- No airborne tests of the above type appeared to have been conducted thus far with a standard of analytical sampling equipment capable of identifying all of the potential contaminant compounds which may enter the cabin air from the engines;
- No test data appeared to have been made available from the oil manufacturing companies, which lists all of the compounds which may be released from engine lubricant oils as a result of leakage into air conditioning bleed air from a defective engine or APU oil seal. This includes conditions where such oils and/or their products undergo thermal degradation;
- Many of the potentially harmful compounds which, may be produced by such oils apparently have no available or reliable inhalation dose/effects data available.

In 2007, the UK House of Lords undertook another general small-scale review into air travel and health. [217] Very little expert input was requested and the report found that the link between air quality and health was still not proven. It did however recommend that the Government work with airlines, manufacturers and the regulator to take effective action in preventing oil and hydraulic fluid leakages into the air supply, the Government should conduct an awareness campaign to ensure that pilots reported fume events and establish a medical protocol to deal with fume events. It also recommended that ongoing UK Government sponsored research look into what contaminants were produced during a fume event and be completed *'urgently'*, followed up by an epidemiological study on pilots to ascertain the incidence and prevalence of ill health in aircrew and any association there might be with exposure to the chemicals. The 2007 House of Lords report did little to increase the understanding of the issues relating to contaminated air exposures. The UK Government responded suggesting, the reporting regulations were already suitable and it could only decide how best to proceed with health effects (epidemiological study and medical protocol) after further research had identified what contaminants were present during a fume event. [218]

In 2007, the UK Committee of Toxicity completed an eighteen-month review of the aircraft into the *‘Cabin Air Environment, Ill-Health in Aircraft Crews and the Possible Relationship to Smoke/Fume Events in Aircraft.’* [4] The report concluded: it would be prudent to take appropriate action to prevent oil or hydraulic fluid smoke/fume contamination incidents; it was not possible to conclude that there is a causal association between cabin air exposures (either general or following incidents) and ill-health in commercial aircraft crews; however, a number of oil/hydraulic fluid smoke/fume contamination incidents occurred where the temporal relationship between reports of exposure and acute health symptoms provided evidence that an association was plausible; approaches to exposure measurement should address the widest possible range of potential contaminants from oil/hydraulic fluid that could be analysed and should not focus on only a single chemical group or compound; there was insufficient evidence available to recommend additional epidemiological research on any acute health effects or to justify epidemiological research focusing specifically on OPs; there was insufficient evidence to recommend any specific additional research for any other acute or chronic health effect with regard to oil/hydraulic fluid contamination incidents on commercial aircraft and fume events were reported by the pilots in 1% of flights. The COT report was heavily criticised. [219]

In 2007, TNO completed an ASHRAE report reviewing monitoring technologies for aircraft cabin air. [220] The report found that current knowledge of aircraft air quality and knowledge is limited.

In 2007, ASHRAE published its non-mandatory standard involving air quality in commercial aircraft. [10] A range of contaminant sources are identified that can effect cabin air, including engine oil, hydraulic fluids and de-icing fluids, which should be addressed in the design, operation, and maintenance of aircraft environmental control systems. Bleed air monitors/contaminant detection systems are recommended to be installed to facilitate maintenance and pilot actions by way of *‘one or more sensors intended to identify a substance or substances indicative of air supply system contamination by partly or fully* *pyrolyzed engine oil and hydraulic fluid*'. A further guideline to support the air quality standard is in the public review stage. [221]

Other studies are currently underway but not yet completed, such as the Australian 2008 CASA led Expert Panel on Aircraft Air Quality (EPAAQ) reviewing cabin air quality toxicity and risks to human health, specifically the effects of aircraft contaminated air. [222]. Likewise in 2009 the European Aviation Safety Agency, EASA, published an advance proposed rulemaking amendment calling for submissions relating to Cabin Air Quality onboard Large Aeroplanes. [223] While this inquiry has not been completed, the author has been made aware that the EASA A-NPA draft conclusion will be that up to now there has been *'no new evidence on the issue'* with additional reference made that the UK Cranfield air monitoring study *'may result in more reliable information'* and a further review group is likely to be established, [224] such as those being undertaken under the US FAA funded ACER work. [225]

5.4 Discussion

The cockpit or cabin of an aircraft is a unique environment. It is a specialised working environment for aircrew that must not be equated with workplaces at sea level, or workplaces where specialised ventilation and escape are possible. [12]

The process of aircraft pressurisation means that the working environment is hypoxic in which flying crew are required to conduct complex operations requiring high order cognitive skills and coordination expertise. [12] Flight attendants may be required to direct emergency procedures requiring composure and confidence. Anything that may have an impact on the provision of these tasks can have serious consequences. A leak of oil from an engine operating at altitude with a lowered partial pressure of oxygen would see most of the oil pyrolise once it leaves the confined conditions of temperature and pressure operating in the engine. Leaking super heated synthetic jet engine oil into the cabin air releases a wide variety of breakdown products. [94,95,97,129,153,154,155] The lubricant substances are radically transformed, and the cocktail of chemicals that could form are dependent on temperatures. Compounds include carbon dioxide, carbon monoxide, partially burnt hydrocarbons (including irritating and toxic by-products, such as acreolin and other aldehydes), and TCP (which is stable at high temperatures). These contaminants will be in gas, vapour, mist and particulate (smoke) forms. These contaminants cannot be classified as being of low toxicity. [12] Product information such as labels or MSDS for commercially available jet oils note:

- Prolonged or repeated breathing of oil mist, or prolonged or repeated skin contact may produce nervous system effects;
- Toxic fumes may be evolved on burning or exposure to heat;
- Product may decompose at elevated temperatures or under fire conditions and give off irritating and/or harmful (carbon monoxide) gases/vapours/fumes. Symptoms from acute exposure to these decomposition products in confined spaces may include headache, nausea, eye, nose, and throat irritation.

Where exposure may be to high levels of airborne contaminants, it is not unreasonable for signs of irritancy and discomfort to be observed. [12] A substantial number of studies have been carried out investigating chemical contamination of aircraft air. However, in considering the situation where an engine oil leak occurs, it is difficult to extract useful information from these studies. Some oil manufacturers, aircraft manufacturers, aviation industry reviews and airlines have acknowledged the oils are hazardous or harmful with irritancy and other short-term effects occurring to varying degrees.

The airline industry states a causal relationship between contaminated air and adverse effects cannot be proven as no monitoring data has been undertaken at the time of epidemiological studies. [3] Others suggest epidemiological studies or design of a medical protocol are not warranted until it is known if the substances identified in cabin air studies can be at levels to cause harm. [4, 218,226] The US NRC and House of Lords reported no studies had been undertaken during contaminated air events. [2,227] Others have suggested paucity of data or inadequacies in methods and instrumentation used for measuring preclude definitive conclusions. [118] Some suggest the air monitoring data available proves cabin air is acceptable, [228] while others state there is no need to monitor air during contaminated air events and air is normally only monitored on certification. [227,228] CASA and airline executives, despite knowing there was a problem with the BAe 146 spanning back over almost 15 years suggested:

- *'The cabin environment in the BAe 146 aircraft is as chemically clean, if not cleaner than other transport aircraft in service today. In terms of National standards for offices and workplaces, these aircraft are far cleaner (less contaminated) than their earthbound counterparts.'*[51]
- *'The cabin is probably the best work environment we have got. It has got a filtration system and air exchange system that is above an operating room in a hospital. It takes in air at an altitude where there are no allergens or toxins. This is why since the no smoking ban asthmatics have found flying great; there is no problem at all. It is a very clean environment.'* [53]

Industry reviews of air quality suggest that in normal operating conditions, the air quality is satisfactory and that contaminated air events occur only rarely are episodic in nature, and occur when there is a systems failure. However, this view ignores the fact that it has long been recognized that engine oil seals have very specific design and operation criteria with performance losses occuring fast when wear occurs due to shaft vibration or in certain thermal or transient conditions and may not be as efficient in transient (acceleration, deceleration, warm up) operation. [36,56,57,58] In 1955, it was recognized that sealing properties for high speed and high rotative engines were complex and would become more so in the future as temperature requirements rise. [33] In 2005, the early oil leakage rate as a function of engine seal design was recognized with the comment that seal design had been improved to the extent that oil seal leakage concentrations into bleed air was *'negligible'*, while others acknowledged that all engines leak oil as a feature of the design of using bleed air for the air supply. [51]

Oil leakage has long been recognized as the main source of bleed air contamination with a small leak in the front end of the compressor resulting in some of the oil finding it's way into the bleed air supply [35] along with others recognizing oil leakage is the predominant source of fumes. [12,53,55,170] Loss of oil arising from permissible leakage past certain seals is one of the main sources of engine oil loss, as distinct from evaporation. [42] The need by the operators and manufacturers to reduce fuel consumption is in part accomplished by raising operating temperatures resulting in higher heat loads placed on lubricants requiring the increase in oxidative and thermal stability of some current (Type 2) lubricants. [76] The higher temperatures that the oils were exposed to resulting in oil breakdown and deposits (coke, sludge) led to military thinking in the 1950's that the deterioration was caused by impurities and TCP or other phosphorous compounds used as additives. [229] Coking and deposits are issues relevant to today with some fourth generation oils reported to have superior qualities over earlier generation oils. As such it can be clearly seen that oil leakage is not something happening by chance on a rare occasion. It is expected and while it may not occur at the same rate it did half a century ago and more, it is a design and operational feature, while mechanical failures can occur on occasion. Failing to recognize the true extent of the design and operational factors involved in oil leakage and suggesting it is a rare maintenance failure only opens the door for serious under-estimation of the problem.

The toxicity of synthetic lubricants has a long history. However, the author was not aware of the extensive 1950's and 1960's research until recently and as such it is not widely known. The use of aircraft bleed air dates back to around the second World War in military applications, while since then engine temperature requirements continued to rise with higher performing engines. The toxicity of the synthetic lubricants can be traced back to at least the early 1950's with a major study undertaken for the USAF in 1954 based on increased military and industry concern with the use of oils utilised in contact with raised temperatures. Toxicity hazards were clearly highlighted when the synthetic oils were heated to above 600°F (316°C), [39,40] a temperature commonly encountered at the high stage compressor outlet in modern turbine engines) with thermal decomposition products seen as more toxic than undecomposed materials. While limited military studies continued over the next few decades (1961, 1979, 1989, 1995), indicating a variety of toxicity issues, there was clear awareness and concern shown by some oil, engine and aircraft manufacturers. However such concerns appear to have dissipated by around 1970 with no evidence supporting that the toxicity hazards no longer existed. A variety of manufacturer and Government studies of the oils and pyrolysis and breakdown compounds have taken place over the years, with findings of interest, however, these have generally been dismissed as causing irritancy only, despite the evidence showing concerns about toxicity.

In addition to the aviation oil studies, a growing number of aircraft air monitoring or air quality studies have taken place by airlines, manufacturers, aviation industry organizations, Governments and the military in limited cases. Specifically, when reviewing the air quality studies that have been undertaken, the following conclusions can be drawn:

- Many studies have not used techniques suitable for the specific situation of monitoring for contaminated air.

- The review undertaken showed that 38% of the air quality studies were not monitoring for contaminated air events and not using techniques that would capture these;
- None of the studies undertaken except one brief ‘minor’ fume event took place during a contaminated air event;
- Epidemiological data reviewing adverse effects was rare and of poor quality;
- No epidemiological data (even if of poor quality) were undertaken during a contaminated air event. Studies undertaken shortly after contaminated air events were generally of limited value and none involved any physiological testing;
- Strong industry affiliation bias shown in studies suggesting air quality was acceptable, with a greater likelihood to suggest acceptability shown in the general air monitoring studies:
    - 60% of general air monitoring studies (not looking at contaminated air) suggested the cabin air quality was satisfactory,
    - 27% of specific contaminated air monitoring studies suggested the cabin air quality was satisfactory;
- TCP was identified in 48% of studies specifically looking at contaminated air and 60% of the specific contaminated air studies identified oil as the source or part of the source;
- There is evidence to support that data on contaminated air substances were withheld from public review.

In general, most studies or reviews of air quality on aircraft indicate that cabin air quality is satisfactory or fail to comment clearly otherwise. However, few have investigated air quality after engine oil or hydraulic fluids leaks and are therefore unsuitable for comparison purposes. There are a number of problems associated with interpreting this data:

1) Investigations that do not mimic the conditions of flying will not be representative of conditions during flight. Studies conducted on the

ground, with aircraft doors open and with engines not on full load will not allow suitably representative data to be collected.

2) Investigations that report contaminants during normal flight are not relevant in considering the types of contaminants and their concentrations that may occur during oil leaks. Many authoritive studies and reviews [95,157,217] miss this significant point and continue to persist with the argument that as levels during normal flights are within acceptable levels, there is no problem. As an example, the UK Government continually states the following when asked about contaminated air quoting the EU and industry funded CabinAir project: *'Studies such as the European Cabin Air project have shown that normally the levels of chemical and biological contaminants in aircraft are less than in many work environments such as office buildings'* [168,226,230] This is a problematic finding as the CabinAir project did not set out nor did it monitor contaminated air flights with techniques that enabled capture of data of such events should they have occurred. [168,169,171]

Most studies fail to appreciate this key point. This argument is especially concerning when virtually no air quality study has taken place during a contaminated air event, except one case (Muir 2008), where a *'minor fume'* event occurred in flight on one occasion, but was still less than another aircraft type monitored on the ground in the hanger. Only suitable analysis during an oil leak can measure contaminants arising from an oil leak. However, there are studies available that were undertaken some time after or not associated with a fume event, with significant data available for review Fox 1997/2000 (Ansett); CAA 2004; Fox/Honeywell/SHK 2000 (Sweden); Fox 2001, Muir 2008). However, the most comprehensive study being the Swedish BAe 146 study (Fox 2000) was misinterpreted upon analysis with the use of ground based exposure standards, which has been the same case for all other studies to date.

3) Investigations have not attempted to capture the possible range of contaminants that may be found on aircraft. Many studies have captured conventional contaminants with mandated standards, such as carbon

dioxide, carbon monoxide and ozone. Some others have attempted to capture volatile organic compounds or particulates. Few have specifically looked for contaminants of interest, such as N-Phenyl-alpha-naphthylamine or isomers of tricresyl phosphate, especially including all the ortho-isomers. However, very often, such studies are cited uncritically by industry spokespersons noting that there is no contamination problem.

4) Investigations have been conducted using inappropriate sampling techniques. One of the most serious problems is sample collection for later analysis. The volume of Tedlar bags and Summa canisters may not allow collection of sufficient amounts of airborne contaminants for analysis. While gases and vapours form true solutions in air, suspended materials do not. Mists and aerosol particulates will settle under the force of gravity, and where they coalesce or adhere to the walls of their container, the concentration of the mist in air would drop dramatically, leaving only a very low vapour residual. Subsequent extraction of this sample for analysis would be as the residual vapour, and only very low levels would be measured. This will lead to a false negative analysis result when collection of a mist of a low volatile material at relatively high levels is then extracted in low concentrations as a low vapour pressure vapour. Any sampling method that relies on sample collection of an air sample containing a mist, and analysis of a residual vapour (when all the mist has settled) could underestimate exposure by orders of magnitude. Virtually all monitoring outlined above which relies on sample collection for later analysis is severely flawed. [66,183]

5) Investigations have been conducted using inappropriate or poorly selected analytical methods. Methods for the analysis of volatile organic contaminants will provide inaccurate measurements of semi-volatile chemicals and will not provide measures for non-volatile chemicals, such as tricresyl phosphate. Such chemicals require very specific testing procedures. This again allows the possibility of false negative results to occur.

6) Many studies report that measured air concentrations commonly conclude that their observed results are within *'acceptable levels'* as

specified by occupational threshold limit values or similar. There are a number of criticisms of this approach. These include:

- Organisations which recommend values for exposure standards usually acknowledge that their recommended values do not protect all workers as they in fact only protect *'nearly all workers'*; The uncritical acceptance of these values by workers in the aviation industry as a suitable reason to accept the findings of some reports delays recognition that there is a problem that requires attention;
- Exposure standards are established to assist in the protection of workers. They do not apply to people who are not working on the aircraft (for example, passengers). They do not apply to the young, the elderly, the unborn, the sick, the immunologically compromised, individuals with differing levels of liver cytochromes P450s or the chemically sensitive. All may be found as passengers on aircraft;
- Exposure standards are not available for all chemicals, including many chemicals reported in some studies investigating contaminated cabin air;
- Exposure standards apply to individual chemicals and the synergistic effects of chemicals in the aircraft cabin air or bleed air supply are not covered and have never been considered.

7) The impact of exposures at altitude has not been properly considered. Exposure standards should not be applied at altitude and a number of key points are worthy of comment.

- The ACGIH recommends a minimal oxygen partial pressure of 132 mm Hg up to 5000 feet. [231] 132 mm Hg is seen as an oxygen deficient atmosphere and at elevations greater than 8000 feet, the partial pressure of oxygen is expected to be less than 120 mm Hg. [231] The cabin environment pressurized to approximately 8000 feet is therefore a hypoxic environment to which exposure standards cannot be applied as they are on the ground;

- Other problems with atmospheric pressure and lowered oxygen concentrations include changes in sensitivity to toxic exposures (for example, the toxicity of carbon monoxide is 50% higher at 8000 ft than at sea level), and the possibility that incipient hypoxia may lead to higher respiratory rates and therefore increased exposure;
- The interaction effects of hypoxia/low humidity have not been studied adequately, but are unlikely to be insignificant;
- Current exposure standards are not applicable: In interpreting the results of monitoring studies, most reports exclude the impact of the hypoxia of flying in a pressurised cabin. Flying crew are required to conduct complex operations requiring high order cognitive skills and coordination expertise. Flight attendants may be required to direct emergency procedures requiring composure and confidence. Anything that may have an impact on the provision of these tasks (for example, chemical contamination) can have serious consequences. A lowered level of oxygen may in turn, have an impact on the emergence of adverse health problems to toxic exposures.
    - *'The aircraft cockpit and cabin are unique workplaces that cannot be compared with industrial and other workplaces on the ground. Aircrew members are required to perform complex tasks requiring high level cognitive skills, which may be much more sensitive to insult by hazardous contaminants in the smoke/fumes, such as Tri-Cresyl Phosphate (TCP). Therefore, the maximum permissible limits for safe exposure recommended by the Occupational Safety and Health Administration (OSHA) of USA, and American Council of Governmental Industrial Hygienists (ACGIH) for industrial workers cannot be applied to aviation.'* [8]
    - '*Current safety standards differ from air quality levels that will provide a perceived acceptable level of customer and*

crew satisfaction. Contaminant levels may be well below recommended levels in currently accepted safety standards yet generate complaints, because they act in synergy with other contaminants or because some standards may be outdated and not have incorporated more recent scientific and medical evidence. In addition, extenuating circumstances on board aircraft (including humidity and cabin pressure) have not been studied to the extent that a new standard can be proposed which incorporates these factors or identifies interactions between factors'. [129]

- *'Can such terrestrial standards (OSHA and others globally) be applied to workers in the air (cockpit and cabin crew) and passengers with rationale… probably not.'* [3]

8) Airborne monitoring ignores exposure from skin absorption, known to be a significant route of exposure for at least some organic phosphates, including tri-orthocresyl phosphate. [232]

9) Where exposure may be to two or more contaminants, the individual exposure standards for each individual contaminant should be reduced proportional to its concentration. Statements that all chemicals were within their representative exposure standards are not appropriate in exposures to mixtures of chemicals anywhere, but especially at altitude. Synergistic effects of the heated inhaled contaminants must be considered, however are not.

10) Other factors due to the manner in which air is circulated in planes, may also have an effect, such as humidity, temperature, or exposure to contaminants such as carbon dioxide, carbon monoxide, ozone and particulates.

11) Current risk assessments of chemicals are based on single compounds and may underestimate the toxicity of a mixture and interactions may change the dose-response relationships leading to adverse effects at lower levels than expected or additional toxic effects not predicted with individual components. Experimental data on effects of mixtures have

been obtained from studies using high levels of exposure and may not predict what will happen at lower levels e.g. transcriptional level of the genome. [233] This is of great importance to the unborn.

There are considerable methodological problems with the studies that have been carried out. Monitoring was often carried out using inappropriate techniques and conditions, using analysis for vapours only with mists or semi volatiles coalescing to surfaces, unknown maintenance condition of aircraft tested and most importantly not carried out during a fume event.

Aircraft air quality standards (of which there are very few available) were originally set in military safety and health specifications. [234] *'These standards were adopted directly for civilian application by engineers who had very little understanding of the chemistry or biological rationale for inclusion in various measurement parameters.'* [234] Additionally, the selected few limits that exist under the airworthiness regulations (CO, CO_2, O_3) were established as safety standards and were not intended to address health and comfort issues. [234] Standards used by engine manufacturers in a maintenance or certification role, measured only formaldehyde and acrolein for oil contamination. These have since been developed into SAE Aerospace Recommended Practice ARP 4418 measuring a number of additional substances, however not TCP and was *'patterned after the Rolls Royce methods of engine certification testing.'* [234,235] The standard generally used 1/10th of the TLVs and assumed TLVs were acceptable for occupational and non-occupational roles and would provide a safety factor for unidentified contaminants, however some substances such as CO_2 utilized a far lower threshold of 9 ppm based on odour thresholds in engine laboratory testing relating to comfort. The SAE ARP 4418 is intended to bridge the gap between health, comfort and safety. ASHRAE, like the SAE committee, recognized it did not have the expertise to set limits for comfort and health but has continued work in this area. [234] Current air standards assume that all the air entering the Environmental Control System (ECS) is clean, however, this is not the case as shown in SAE ARP 1539B. *'Mandating more air of uncertified quality to ensure that cabin air is free of contaminants will not ensure a safe, healthy or comfortable environment.'* [234] It is suggested that what is required is *'performance based regulations permitting technical* *solutions, in conjunction with monitoring of environmental parameters'* thus *'ensuring health, safety and comfort objectives are met.* [234] Whether such SAE/ASHRAE standards take into account the limitations addressed above needs to be closely reviewed by specialists without industry/Government interests. On the other hand, exposure standards which are supposed to be health standards were more often set as what was achievable by industry, as previously identified.

There have been numerous studies undertaken of the oils under laboratory conditions and these provide evidence that oil pyrolised at high temperatures must be the focus along with case controlled studies. This is especially important considering that there is significant acknowledgement and data to support that exposure to oil and similar substances at altitude is occurring. The Swedish BAe 146/Honeywell data showing the heated synergistic cocktail of substances incapacitated the crew. The standard of monitoring and interpretation of results cannot, at this stage, support an understanding of this problem and the use of exposure standards must be reviewed.

The Swedish 1999 BAe 146 incident is the best demonstration supporting that exposure standards should not apply in aviation. The fumes were not obvious, occurred over numerous sectors, all crew were affected to varying degrees, with the pilots incapacitated and passengers unusually, according to the captain, were difficult to wake up after landing. While oil leak defects were found, all levels of contaminants were said to be below exposure standards, despite many substances having no set standards. This event clearly demonstrates that the effect at altitude in an aircraft environment to a mixture of highly heated chemicals reacts completely differently to the individual substances on the ground and supports the finding that terrestrial based exposure standards are inapplicable in an aviation setting. In this case, there was no follow up of crew or passenger adverse effects and in the case of the captain at least, serious long-term adverse effects have been reported. Additionally, the failure to clearly advise that TCP and other hydrocarbons were found is in keeping with the pattern of keeping information to a minimum at best.

Aircraft contaminated air detection systems fitted in the flight deck on the other hand has been recommended by many authoritive bodies, yet still remains unaddressed. [2,10,27,34,236,237,238,239] Therefore, on routine everyday flights, the pilot has no form of detection system other than his/her nose and the trust that industry studies (above) are acceptable as stated. This is a major flight safety issue and importantly the FAA recognized in 2002 that this was a breach of the FAR airworthiness regulations, which require the air to be free of *'harmful or hazardous concentrations of gases or vapours'*. [240] This regulation has been around since the 1950's and has European equivalents. The FAA stated:

- *'No present airplane design fulfils the intent of 25.831 because no airplane design incorporates an air contaminant monitoring system to ensure that the air provided to the occupants is free of hazardous contaminants.'* [241]

Likewise, the call for aircraft air cleaning/bleed air filtration technology [10,27,107,237,238,239,242] has gone unanswered, again with the airline industry suggesting inappropriately, that the studies to date present no problem with air quality. There has however been some very limited progress in monitoring techniques ranging from manufacturer or airline oil contaminant ground detection equipment [243,244,245,246] to air sampling techniques and analysis. [102,103,184] Additionally, various funded sensor research projects have continued to be undertaken. [225] However, to date, this has not materialized into aircraft bleed air detection systems. At the same time that the FAA has suggested it is monitoring the various research projects including the FAA funded ACER work as well as the ASHRAE Battelle phase 2 study and working with EASA to develop common standards for monitoring aircraft air and preventing contamination; [247] legislation has been passed or in the process of passing in US Congress calling for research and development on effective cleaning and sensor technology and related research. [238,239] Major access problems were identified in the ACER/OHRCA research with the airlines refusing to allow monitoring to take place at the same time as health survey data were collated. [189] This is a significant finding, particularly given this was Congress mandated work funded by the FAA. As such, recent US Senate proposed amended legislation aims to address the access issue, [238] however, the call for research continues without real actions in sight. This is particularly interesting given that it has been acknowledged by the FAA that no aircraft is in fact airworthy, given no air contamination detection systems are installed. [241]

While air monitoring studies that did not specifically look at contaminated air and therefore did not use specific contaminated air monitoring procedures, are of no value in the contaminated air debate, they should not be used to suggest that all aircraft air quality is acceptable and cannot be responsible for adverse effects. Likewise, the specified aim to investigate contaminated air in aircraft does not necessarily mean suitable techniques were utilized. Of those that did not suggest that air quality was acceptable, the data itself must be reviewed since many of the studies found TCP and oil substances in the aircraft air/environment.

The fact that no epidemiological data could be collated during monitoring and all was of little value; this likewise cannot be used to suggest air quality is acceptable. Therefore it is inappropriate for the airline industry to continue stating all air quality testing suggests that there is no problem and could not cause adverse health effects. To suggest that until monitoring takes place at the same time in concert with epidemiological studies; relies upon the fact that the monitoring and analysis have to be suitable. To date, this has not been the case. The UK Government has suggested that health studies can only be undertaken after it is determined what contaminants are in the air. [218] Based on the standard of air quality studies to date and the inappropriate interpretation of the substances found, it is unlikely that contaminants of concern would be found. Additionally, it has been made clear that the major FAA funded monitoring/epidemiological study could not be undertaken, as the airlines would not allow this. The author has also experienced the industry unwillingness to support epidemiological studies even on a limited basis. The difficulties in getting pilots to participate in an epidemiological survey and divulging personal adverse effects contrary to medical certification has been noted by aviation regulators, Governments and the military. [226,248,249]

Apart from the military data obtained and reported, the validity of the test data presented in all the reports cannot all be guaranteed to be a true reflection of the data actually gathered, as commercial interests or biases cannot be ruled out. Many reports had little, if any, independent scrutinizing of the monitoring techniques, equipment, analysis or data collection process used.

Difficulties in utilizing standard or acceptable epidemiological techniques is noted with regard to environmental pathology where accurate historical exposure data are not available, there are no diagnostic markers and the development of ill health may depend on susceptibility factors. [250] Methodological developments in molecular epidemiology, focussed investigation on the toxic mechanism and alternate views on exposure assessment may resolve some of the difficulties. [250] Data other than air quality monitoring and epidemiological monitoring may be required when reviewing oil lubricants and other aircraft contaminants in aircraft and adverse effects. While there are various symptomology that have been highlighted and could be reviewed in case controlled studies, [251] biomarkers for exposure to the engine oil additive TCP are in development. [252]

The problem of contaminated air and the associated toxicity concerns have been known about for over sixty years with the first recorded known case of incapacitation occurring in 1977. There is enough evidence that independent informed experts must address this problem outside the aviation industry. It is inappropriate for the aviation industry to suggest that the variety of complaints is caused by alternative factors including personal factors, work related and other cabin air quality exposures. However, there is very often a commercial conflict of interest that ignores the data that are available. Data, which confirm that contaminated air is a genuine issue and for which suitable data are available should be used to make the case for updated techniques, monitoring such events as well as tracking adverse health effects from such exposures. The health and flight safety issues warrant this. No aircraft is in fact airworthy without detection systems installed for monitoring air quality. Some chemicals already have maximum limits even if these are not applicable to passengers but these are never measured.

A recent example of the likely failure of the system involves an Airbus A319 aircraft that was investigated for oil contamination (seen as an ongoing issue) after reports of adverse effects with no obvious fumes. The extensive tests (appearing inadequate) failed to detect any contaminants of concern and the defect was never determined. [253]

5.5 Conclusions

The conclusions that can be drawn from these studies are that oils, hydraulic fluids and selected other aircraft products contain toxic ingredients which has been known about for over sixty years. These substances can be irritating, sensitizing or neurotoxic. These products can all leak into the aircraft air supply and are not a rare occurrence. Oils and hydraulic fluids are safe as long as they remain in the engines or system for which they are intended; however when they leak into the air supply and cause discomfort or toxicity this is a major flight safety and health concern. When discomfort occurs this is a breach of the airworthiness ventilation regulations, the FARs and equivalent legislation.

The airline industry has insisted that the air under normal conditions is safe and within all limits. It is also stated that under the *'rare'* abnormal event air monitoring has shown that contaminant levels cannot cause a flight safety or health hazard. However, there is evidence that leak events are common and flight safety is being compromised with adverse health effects being reported.

The studies that have been undertaken by the airline industry to demonstrate that the air under normal and abnormal operating conditions are flawed. They cannot be used to justify that the air is of an acceptable standard when contaminated air is present for a number of reasons which include:

- Studies of the heated oils demonstrate that they can contaminate the cabin air with unchanged material, degraded material from long use, combusted or pyrolised materials. These materials can contaminate aircraft cabin air in the form of gases, vapours, mists and aerosols;
- Cabin air sampling procedures have been flawed and inadequate;
- Sampling has effectively not taken place during a contaminated air event. Most sampling does not use techniques suitable for monitoring all types of substances in contaminated air;
- The aviation industry and often Government studies have shown a strong bias and in some cases withheld the actual data acquired;
- Airline studies have often stated the air quality is acceptable when the studies referenced did not investigate contaminated air;

- Epidemiological surveys have not been rigorous or fitted the true definition of the term or done at the time of or following exposure events;
- Exposure standards have inappropriately been used to suggest the air quality is safe;
- Industry studies have inappropriately accepted that the air is safe;
- There is evidence that has shown that contaminated air is occurring and is jeopardizing flight safety and causing adverse health effects;
- It is no longer appropriate to suggest that until high enough toxic exposures in the cabin air can be demonstrated at the same time as an epidemiological study which links this to crew and passenger adverse health, the air is deemed to be satisfactory;
- It is not appropriate to suggest until levels of contamination occur above exposure standards, no further crew or passenger research can be undertaken and no medical protocol can be established;
- The data available to date indicating the awareness of oil seal leakage as a function of using bleed air, data acknowledging leakage is occuring not infrequently, cannot be ignored in favour of monitoring and epidemiological studies that cannot address this unique environment.

The airline industry must take a step back and recognize industry bias can no longer be used to suggest that cabin air is safe based on inappropriate techniques utilized for monitoring contaminated air events. The Swedish BAe 146 incident in 1999 best demonstrates that under an oil leak situation, the pilots were incapacitated and the cabin crew all experienced adverse effects. The synergistic cocktail of heated contaminants found after the event indicates flight deck monitoring can no longer be delayed as all studies suggest the air is suitable and yet the cocktail incapacitated both pilots, with long-term ill health following in the captain’s case.

The ability to measure the air for contaminants has been demonstrated successfully by the RAAF and others. Real time measuring technology also exists; the technology is used in many other enclosed spaces such as mines, spacecraft or submarines. Such technology is also widely used by the military.

The technology should be adapted for flight and introduced into the flight safety critical environment of the cockpit as a matter of urgency. This step has been suggested by numerous safety authorities and aviation bodies for many years but has yet to occur. Research in many cases is being hindered and the cabin air issue is sent around in circles. Until aircraft air monitoring detection systems are fitted to all aircraft, no aircraft meets the FAR/JAR aviation airworthiness regulation 25.831b and its equivalents.

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6 Frequency of Fume Events

6.1 Introduction

Aircraft cabin air being supplied from the engines or the APU is known to become contaminated with hydraulic fluids, engine oils, and the pyrolysis products of these. This occurs as a design flaw consequence of using bleed air, exasperated by inadequate or lack of appropriate maintenance action to rectify or prevent such leaks from occurring. The aviation industry has repeatedly and continues to claim that contaminated air events are rare and there are few documented fume events. This interpretation of the problem requires review to determine the accuracy of this statement and the reasons behind why the industry continues to make such statements. What percentage of these contaminated air events are actually reported by aircrew is unknown although it has previously been estimated that less than 4% of events occurring are actually reported by airline pilots. [1] This chapter reviews the information on frequency of events that have been identified by the author from a variety of sources. A number of databases showing contaminated air events will be presented, with a thorough analysis of the UK Contaminated air events database collated by the author. [2] Trends and significant issues will be highlighted from within the contaminated air database of events. These will then be compared against aviation industry claims and used to identify the significance and impact on flight safety.

EASA clearly demonstrated the industry view when stating in 2009 that the frequency of cabin air contamination by bleed air is *'relatively low'* (rare) with *'incidents occasionally reported.'* [3,4] However at the same time the regulator stated that *'the vast majority'* of fume or smoke events *'are associated with an abnormal leakage of engine or APU lubrication fluid (aviation engine oil).'* [4]

The ASHRAE air quality standard terms contaminated air events as *'episodic events'* and states that such events *'with proper maintenance, operation, and design are anticipated to occur infrequently.'* [5] Likewise the multimillion-dollar FAA funded ACER research advises *'rare instances of smoke in cabin type air quality incidents have been reported.'* [6] Evidence is available to show that while some aircraft do report more fume events than others, there is significant under-reporting of such events and what is reported is often limited in data and not collated, resulting in grossly inaccurate statistics on the frequency of the events. Many contaminated air events go unreported to aircraft operators. Of those incidents that are reported to aircraft operators, many are not reported to regulatory authorities and of those incidents that are reported to regulatory authorities, not all are added to relevant databases or sufficiently investigated with most investigations found to be inadequate. [7]

6.2 Sources of the problem

The aviation industry itself acknowledges that air quality exposure events are primarily due to oil leaking into the air supply. Such admissions are important when reviewing the frequency of events and come from a wide range of sources including company documents, industry and government submissions to Government Inquiries, industry committees and reports. A 1981 Society of Automotive Engineers (SAE) aerospace information report stated: [8]

- *'Engine compressor bearings upstream of the bleed ports are the most likely sources of lube oil entry in the engine air system and thence into the bleed system contaminating the cabin/cockpit air conditioning system.'*

In 1983, Mobil advised cabin air contaminated with any lubricant or the decomposition products of such lubricants could *'be generally traced to improper design, improper maintenance or malfunctioning of the aircraft.'* [9] Mobil further advised that with regard to odour formation from jet oils, reported by operators from time to time, odours were more likely to be generated when oil is exposed to conditions that result in thermal degradation such as occurs when oil leaks past a seal. [10] In 1990, it was stated at a major industry committee meeting that *'The approach adopted some years ago by Rolls Royce was to recognise the fact that in the majority of instances where cabin air contamination was a problem, it was mostly associated with small leakages of synthetic lubricant from bearing seals etc.'* [11] Allied Signal advised, after testing Dan Air BAe 146 aircraft reporting objectionable odours described as *'dirty socks'*, that *'little work had been done to pinpoint the chemicals causing such odours but appeared to be 'breakdown products of the oil.'* [12]

British Aerospace (BAe) stated that *'Every engine leaks oil from its seals and bearings...'* [13] and that *'The air supply is protected from contamination by seals, which achieve maximum efficiency during steady state operation. However, they may be less efficient during transients (engine acceleration or deceleration) or whilst engine is still achieving an optimum operating temperature.'* [14,15] Rolls-Royce stated that *'Avoiding oil leakage out of the bearing chamber, and subsequent leakage into the turbomachinery annulus and* *the customer bleed offtake is a joint effort between the secondary air system group and the oil system group. The overall system has to be capable of ensuring that all relevant seals are sealed across the whole operating envelope of the engine. The development of sealing concepts and the simulation and reliable prediction of the sealing; performance is of major importance in this context… …it must be ensured that the system operates safely under all engine conditions, e.g, during transient manouevres.'* [16] Lufthansa Cityline advised that *'labyrinth seals which are used in jet engines operate pneumatically and react slightly delayed by technical design. When a jet engine moves from idle to full take off thrust, first of all the oil pressure will rise before the seals will completely close. This way, it can happen that small amounts of oil particles get into the bleed air ducts. However, when the throttle is advanced carefully, the seals will close in due time'.* [17] On the other hand, the former Director of the Aerospace Medical Association suggested that contaminated air *'exposures occur only when there is a mechanical malfunction… Hence, we have an engineering problem.'* [18] This clearly ignores the issue that oil seals leak by virtue of their function and design.

BAe clearly linked the majority of fumes to leaking oil when stating *'Reports of cabin air odours have been received from time to time and have predominantly been determined to be due to minor systems failures such as leaks from oil seals on the aircraft engines or APU.'* [19] A BAe manufacturer's service information leaflet again identified that smells associated with bleed air supplies based on *'operator experience indicates the most likely sources are oil contamination of the engine/APU bleed air.'* [20] Ansett also directly linked the fumes associated with its BAe 146 aircraft *'predominantly'* as Mobil Jet Oil II. [21] The airline convened an external panel, which linked the short-term symptoms reported on the BAe 146 as well as other aircraft generally to system defects or inadequate ventilation. [22]

The Civil Aviation Safety Authority of Australia (CASA) importantly spelt out that by design all engines will leak oil when stating *'All aircraft from time to time suffer fumes within the aircraft… that is a feature of the basic design of air-conditioning systems in aircraft, being bleed air from engines and that on occasions engines leak.'* [23] CASA advised that *'Early engine problems (BAe*

146) included poor reliability of the engine bearing oil seals, which resulted in engine oil mist being present in the air which is bled from the engines for cabin air conditioning.' [24] The CASA remark minimising the extent of the problem by stating that such leaks occur *'from time to time'*, will be shown to be inaccurate. However, this is a common industry position during an admission that oil does leak, that it does so only sometimes or rarely.

Another example of the acceptance of oil leaks in aviation as satisfactory can be seen by BAe stating that *'in the early 1990s, we had a problem which was that our aircraft did have oil leaks which were greater than the industry standard... the aircraft is now in a situation where it does not leak oil at a frequency any greater than other aircraft.'* [13] BAe went on to say it had responsibly introduced modifications to overcome the problems and that all remaining issues were comfort ones only, rather than safety issues, indicating there may be a *'general industry wide, all aircraft issue relating to cabin air quality.'* [13]

The Civil Aviation Authority of the United Kingdom (CAA) acknowledged that while the exact cause of a crew member incapacitation was not known, *'the most probable source is oil leaking from the engines or APU and contaminating the air supply to the cabin and cockpit through the air conditioning system…'* [25] The CAA further supported their view that oil was the problem in stating that the *'potential'* cabin air contamination was caused by *'abnormal concentrations of noxious gases or vapours',* [26] and that *'contamination of the ventilation systems by engine oil fumes was the most likely cause'* and *'subsequent CAA investigations found no weight of evidence indicating that other causes were involved.'* [27] One of the few extensive investigations to take place by the CAA found that the cabin ductwork was *'contaminated with a carbonaceous material containing chemicals entirely consistent with the pyrolysis products of aircraft engine oil.'* [27] The CAA had previously issued an Airworthiness Directive (AD 003-10-2002) based on the manufacture's advice (BAe SB 21-156) that on some older aircraft the sound attenuating material surrounding the ducts was found to be *'heavily contaminated'*, 'predominantly composed of *'engine oil and it's breakdown products.'* [28] CASA stated that *'sound attenuating material used in the air-conditioning ducts can absorb oil and can become a source of persistent air contamination.'* [29]

On occasion, certain sectors of the industry have clearly acknowledged the source of the fume events, however often this information is not publicly available. The Australian Transport Safety Bureau (ATSB), which had investigated a number of similar events, stated *'The failure of oil seals has been a common factor in the majority of those incidents.'* [30] British Airways franchise operator, Citiexpress, stated in an Air Safety Report (ASR) from 2005 that *'Oil leaks within the engine/APU have been noted in the past to be the major cause of the reported contamination.'* [31] Lufthansa CityLine reports in it's Avro RJ newsletter that despite numerous modifications and procedures over the years, Technical Log entries and aircraft groundings still happen due to smell events from different origins (oil, de-icing fluids, etc) [17] The UK AAIB supported this view when stating: [32]

- *'These reported events all had a common theme; oil contamination of the air supply from either the APU or the engines. Contamination of the cabin air supply by oil products has occurred from both the APU and the engines, with some regularity, on various aircraft including the BAe 146.'*

Industry bodies are rapidly and increasingly recognizing that oil fumes do occur. Industry recognition is best evidenced in the following chapter of this thesis and can be seen as an ever changing source. ASHRAE for example has stated that *'The APU inlet and engines can potentially be an entry point for hydraulic fluid, fuel, oil and deicing fluid.'* [5] Such incidents including worn oil seals or mechanical failures within the APU or engine are minimized by proper design, operation and maintenance. EASA advised in a similar manner that: *'Under certain fault conditions (e.g. engine or APU oil seal or bearing failure, engine or APU maintenance error/irregularities, or design deficiency), engine or APU oil, hydraulic fluid, fuel, de-icing fluid and the corresponding pyrolysis products may contaminate the bleed air, which then enters the cabin air supply and can be inhaled by the aeroplane occupants.'* [4,33,34]

6.3 Under-reporting of contaminated air events

Clearly, accurate and complete reporting are absolutely vital so that information can be listed, chronicled and shared between the various bodies within the aviation industry to ensure safe flight is not being compromised. As shown, there are a variety of reporting methods available including mandatory and non mandatory formats. However all contaminated air events or suspected contaminated air events are to be considered aircraft defects and must be reported by the aircraft captain every time. The question therefore must be, is the system working, are the events actually being reported and how often are contaminated air events occurring? Under-reporting is however a very serious issue, that is not recognised by many. The British Airline Pilot Association (BALPA) asked the CAA to help it with an independent *'Report it Campaign'* to understand the scale of the problem. [35] However, BALPA was advised by the CAA that it *'did not have any evidence of under reporting from aircrews and that the existing reporting arrangements appeared to be working satisfactory'* and they were *'concerned that the "Report it Campaign" might undermine the current reporting process.'* [35]

The CAA continued to refuse to accept under-reporting over the years by stating all pilots took aviation safety seriously and would never deliberately fail to report occurrences involving impairment and there was no evidence of under-reporting. [36,37] The denial in facing under-reporting was clearly evidenced by the CAA Chairman's response when accused of accepting under-reporting as a means to protect the industry and those who funded the CAA. [38] The CAA Chairman suggested that not only was this profoundly incorrect but to accuse the CAA of ignoring under-reporting, showed a complete lack of understanding of the *'strong safety culture'* in the UK aviation community.

In some cases, false or limited information has been provided, indicating that fume events do not all have to be reported. As an example the CAA advised the UK Committee of Toxicity (COT) incorrectly on the reporting requirements and as such, the COT final report incorrectly states that *'Pilots do not have to make a mandatory entry in the Tech Log regarding cabin air events'* and *'Pilots do not necessarily have to make an ASR in relation to cabin fume events'*. [39] While the CAA acknowledged that *'the reporting of smells or fumes associated with 'ill defined health effects such as headaches and nausea'* might be interpreted subjectively and not reported, [37] this failed to identify that the regulations require all contaminated air events to be reported as a defect to the airline and to the national regulatory authority as previously acknowledged by the Government, regulations, guidelines and airlines. [40,41,42,43,44,45,46,47,48, 49,50,51,52]

The COT committee due to limited and selective provision of information by the CAA, failed to understand that the UK Mandatory Occurrence reporting (MOR) system required all cases of toxic or noxious fumes, including suspected oil fumes to be reported. [44] This error was not corrected by the CAA and therefore the COT final report failed to identify that under-reporting was taking place. In evidence obtained under the Freedom of Information Act 2000 (FOI), it was found that the pilot union, BALPA further endorsed this incorrect view when advising the COT Secretariat that *'there was no mandatory requirement to make a tech log entry.'* [53] The BALPA statement made by a commercial airline pilot and union representative, clearly demonstrated the problem with an inaccurate statement that fume events only needed to be reported *'if there was an 'electronic indication of a fault' related to cabin air.'* The BALPA comment was inappropriate as there is no monitoring of cabin air quality in aircraft and all defects have to be reported in the aircraft technical log in the UK as well as internationally. [45,47,49,54] Despite the regulations FlyBe, a UK airline advised the CAA it had not reported fume events under the Mandatory Reporting Scheme (MOR) as it did not believe such incidents effected safety. [55]

Fume events are not really seen as a regulator or aviation safety responsibility and are often brushed aside as not being their responsibility. Clearly, if the regulator fails to take any real responsibility or interest, then so will the airlines. The knock on effect is to give crews no reason to report all events. Especially if to do so may jeopardise their position. [7] CASA stated that *'Oil fumes are more of a health problem than an aircraft technical defect as not all pilots are affected'* [56] and that toxins in the cabin air were an OH&S issue and outside its expertise as an aviation regulator, which was charged with short and medium effects on flight safety. [23] In a further example of inaccurate guidance and misinterpretation of the regulations, CASA advised in 2002 that prior to the issue of an AD related to air quality issues on the BAe 146, there was no requirement for BAe 146 operators to advise CASA of incidents of air contamination. [57] This was clearly incorrect given that CASA clearly recognised this error two years later when stating all instances of smoke or fumes that adversely affect the quality of the cabin air are considered *'major defects'* by CASA [58] and as such reportable to CASA under the regulations all along. [50,51 ,52]

In addition to contaminated air events being required to be reported to the airline as a defect and to the regulator, there are certain regulations that exist requiring such incidents to be reported to the organisation responsible for the design or the supplier, or organisation responsible for continued airworthiness. [45] Additionally, the holder of a *'Type Certificate'* (aerospace manufacturer) for a particular type of aircraft or engine must report to the regulator certain types of defects or failures including the, *'accumulation or circulation of toxic or noxious gases in the crew compartment or passenger cabin.'* [48,59] However, Boeing, a leading manufacturer, clearly acknowledged that not all smoke/burning odour events *'are reported to Boeing.'* [60] The data collated here will also show this is not happening.

However, under-reporting of contaminated air events is clearly recognised by some leading aviation organizations, as well as other key bodies outside the aviation industry, which have reviewed the problem and data. By reviewing the data, it can be seen that the reasons for under-reporting are broad. [2] In 2001, BALPA undertook a survey of its short haul pilots in British Airways. [1] 93 pilots advised that they had encountered in excess of 1667 contaminated air events that they determined to be mostly related to oil leakage into the air supply system. Of the 1667+ events only 61 or *3.66%* of events were actually reported as required. [2] The Australian Senate Inquiry concurred with this finding regarding the under reporting of fume events when stating that it found *'strong evidence of a tendency of pilots to under-report incidents.'* [61] The recognition of under-reporting dates back many years, to at least 1977. A report regarding a fume event with the US Air National Guard stating *'not infrequently commercial airline flight crews have complained of plastic odour on the flight deck prior to* *engine compressor failures.'* [62] The Director of the Aerospace Medical Association (AsMA) recognised in 1983, when working with the USAF, that *'Smoke and fumes in the cockpit is not a rare event and a clear threat to flight safety due to acute toxic effects.'* [63] The ATSB in Australia came to a similar conclusion in its 1997 investigation of a BAe 146 fume event and found *'smoke and fume contamination of cabin air is neither a new phenomenon nor a particularly rare event and that over time, it has been experienced in many aircraft types.'* [64] The Royal Australian Air Force (RAAF) in 2004 found *'the occurrence of smoke and/or toxic fumes in the aircraft cockpit or cabin is more common than is generally realised.'* [65]

Importantly, the FAA Director for Flight Standards Service clearly acknowledged that fume events were under-reported in 2006 when stating: [66]

- *'FAA's growing concern over numerous reports of smoke/ fumes in cockpit/cabin';*
- *'FAA data analysis indicates numerous events not being reported.'*

This very significant turnaround was preceded by the FAA issuing new guidance on these matters in the form of a Flight Standards Airworthiness Information Bulletin (FSAW) number 06-05. [67] The reason given for issuing the FSAW was:

- *'There have been concerns raised about numerous reports of "smoke/fumes in the cockpit/cabin" events on commercial air carrier/operator aircraft. During the FAA's analysis of this data, it appears as though there are numerous air carriers/operators who may not have reported these events as required by regulation. Prompted by the Office of the Secretary of Transportation's recent interest in these events, the FAA is introducing new policy for PIs to follow.'*

In order to understand the reasons for under-reporting, it is necessary to review the differing views on how oil fumes are regarded by many within the aviation industry. Contaminated air events or fumes have been seen as a non event, a nuisance or a normal part of flight as distinct from a safety issue, thus allowing the problem of under-reporting to be firmly rooted. The Transportation Safety Board of Canada (TSB) stated in an interim report investigating the fatal accident of the Swissair MD11 that crashed into the sea off the Canadian east coast in 1998, that *'within the aviation industry there has been belief that odours are often a 'non event' diminishing concern about minor odours.'* [68]

In 2001, BAe also clearly highlighted the problem faced within the industry:

- *'In the past oil leaks and cabin/flight deck smells and fumes may have come to be regarded as a nuisance rather than a potential flight safety issue. …oil leaks and cabin flight deck smells must be regarded as a potential threat to flight safety not just a nuisance.'* [69,70]

Despite such clear wording, this does not bear any correlation to resolving the problem as education and a change in actions at all levels must occur before the problem is resolved and as will be seen, the problem has remained ongoing.

The view that fumes have been seen as a nuisance over many years rather than a flight safety issue and seen by many crews as a normal part of flying is very common. [7,71,72] As an example, a Canadian union cabin crew survey in 1992 reported that the crew saw *'poor quality cabin air as normal and not worth reporting.'* [73] An ATSB report recorded a BAe 146 Captain's comments that *'most smells and odours were considered the normal environment of the day to day operation of the BAe 146.'* [30] The ATSB report analysis also noted that fumes were a *'recurring'* problem on the aircraft type with fume events considered *'routine'* by operating crew with subsequent diminished awareness of the risks associated. The UK AAIB drew the same conclusion when stating *'Crews are not always fully alert to the possibility of air contamination on aircraft'.* [32] The acceptance of fumes as *'pretty common'* [74] by a captain was supported by an airline doctor, who stated that *'The picture complex that Captain Goulet presented is not uncommon.'* [74] The view that *'oil smells'* on aircraft were not looked upon as serious incidents was mirrored by the Norwegian CAA in 2006, therefore explaining why numerous incidents would not be on its database. [75]

The disregard for the legislation requiring all defects to be reported is evidenced in an internal DHL airlines documentation for pilots which stated *'It is not unusual to experience a low concentration of fumes at the following times: After engine start; during taxi, after T/O- especially a full power T/O, top of descent,* *taxi in. If such fumes become apparent during any of these phases of flight and then dissipate, do not report the occurrence, it is normal*.' [76] The instruction advised for fumes to be reported in the aircraft technical log if they became evident during the later stages of climb/cruise, persist or cause irritation. The CAA, despite clear regulatory reporting legislation, when queried on this, stated *'The inspector found the instruction acceptable.'* [77] This clearly demonstrates that fumes at certain stages of flight are seen as *'normal'* and therefore acceptable by a major international regulator.

In 2009, an oil fume event reported by a passenger to the German aviation authorities, the Bundesstelle für Flugunfalluntersuchung (BFU) and Luftfahrt-Bundesamt (LBA) reported a *'very strong oil smell in the cabin'* on descent until after landing aboard a British Airways A319. [78] The smell was dismissed as *'just an annoyance'* and *'not safety related'* by the cabin crew. The reporter advised that after flight he elected to talk to the pilots in the flight deck, where the smell was *'much stronger'* and *'both pilots had red irritated eyes and gave the impression of being quite fatigued.'* The pilots confirmed the smell was *'very likely a strong oil smell.'* The reporter asked the airline if the event had been reported by the crew to the authorities and was advised that no report had been filed by the pilots or cabin crew and therefore all claims of illness were denied and no further documentation was required to be made available by the airline to the passenger. [79] Enquiries made by the BFU to the UK AAIB on the matter resulted in the airline advising that the crew reported *'only a slight smell of oil*, *therefore a tech log entry was made due to the minor nature and not an ASR*'. [80] This shows the complete failure of the reporting system, understanding of the potential effects of fumes, denial of the event by the operator until questioned by the authorities, downgrading of the event by the operator and uncritical acceptance by the authorities that reports were not made as required. As such, again, the scale of the contaminated air problem remains unknown by the regulator.

In addition to the long-standing problem of fumes being seen as normal and not usually reported unless there is a major smoke event, under-reporting occurs for a variety of other reasons. A few of the reasons include lack of understanding of the health and flight safety effects of exposure to contaminated air, individual susceptibility, industry acceptance as normal and perceived threats to job security. [7]

There is also a long standing culture of crews reporting such events verbally only, [81] and in some cases crews have been discouraged from writing the reports in the aircraft tech log as required. [82] Fumes and their potential health effects are poorly understood by crews and dismissed by many in the aviation industry as not being an aircraft safety issue but a health problem, [13,23,56,83] for which it has been perceived there is no requirement to report such events as they are not seen as an aircraft defect. [56] Crews are advised that inhalation of aircraft oil/fluids is not harmful to their health and that their symptoms are not related to aircraft air. [1] Crews may also be fearful of reporting fumes due to awareness that some crews have been harassed, stood down and or terminated after reporting fumes [84,85] and that others have lost their medical licences. [86,87] Other crews have continued their rostered duty after fume events as the effects are poorly understood, or they have been advised or felt the pressure to continue flying. [1,7,61,64,88] Others report fear of being branded as troublemakers as they would be reporting fumes too often if all cases of fumes were to be reported as aircraft defects. [1]

Failure of some airline engineers to rectify leak problems or to comply with ventilation regulations such as FAR/EASA CS 25.831 does not encourage crews to report fumes, especially when leak incidents are often reported to be rectified at *'company convenience',* [64] *'not safety of flight'*, *'for information only'*, *'no fault found'*, *'report further'* or similar. [30,71] Leak incidents may occur over numerous sectors and are often ongoing over days, sometimes months, [84] with residual contamination being an important problem on some aircraft, [30,89] which therefore also fails to generate reports. Additionally, there is a wrongly accepted practice in the industry of only reporting non-vital defects at the end of the day or duty. For instance, a crew flying from A to B to A to C to A and who experience contaminated air on their first flight from A to B might decide to report a contaminated air defect only after their last flight back from C. This decision process may be due to a lack of perceived importance of the problem, lack of maintenance facilities at B or simply a commercial need to not introduce a delay into the aircraft's busy schedule by an engineering investigation which may delay the aircraft and extend their day at work and which could be investigated at the end of their shift. Even if the crew do report a contaminated air event engineers may have difficulties in tracing and isolating the source, which may result in the aircraft being returned to service with *'no fault found'* and the leak unresolved. [30,83] Honeywell has recognised the difficulty in assessing aircraft bleed air quality in a timely and efficient manner, stating techniques available are *'unacceptable'* from a manufacturing and service perspective. [90] Analysis of bleed air events was deemed very labour intensive with laboratory analysis taking days and even weeks to provide results. [90]

Many in the airline industry have remained very reluctant to accept that under-reporting is occurring, despite the FAA, the lead aviation regulator globally, having recognised that this is occurring. In 1999, the UK CAA advised *'oil leaks were very rare, less than one in every 22,000 flights, spending money on research would be wasteful.'* [91] Ansett Airlines, despite acknowledging that fumes, primarily associated with oil leakage, were reported in every 131 flights (with a fleet of 15 aircraft), equating to one to two reported events per day, advised that fume events are a *'very very rare occurrence.'* [21] Airbus likewise reported that *'APU oil seal leakages are extremely rare and engine oil seal leakages even more rare'* and therefore the reason why no reliable data had been collected. [92] Boeing also stated contaminated air events were *'very rare'* [93] and *'very low*', [94] whilst the UK Department of Transport, EASA and the EU have advised that there are *'occasional fume events'* and fume events are *'relatively rare'*, and *'rare'* respectively. [3,4,95,96] In 2003, the CAA during the same presentation, advised that *'Smoke and Fume Events not uncommon…'* followed by *'flight deck events rare and of low severity.'* [97]

The argument that events are rare is generally based upon no supportive data, however, in cases where limited data are available, the statements that the fumes are rare is not supported by the actual evidence. In the Ansett case above, despite fume events reported as occurring almost daily, a Senate inquiry and the public were still advised the events were *'very very rare'*. In the UK case, the data have been selectively interpreted, with the UK COT committee being advised that oil fumes were reported at one in every 100 flights, yet the engineers in fact confirmed the defect in only one in every 2000 flights. [39] The UK Government has since repeatedly quoted only the lesser figure (fumes in 1% of flights) when discussing the frequency of such events. [95,98,99] Before the US FAA recognised that fume events were being under-reported (therefore no accurate estimation was possible), it had up until 2005 stated that air quality events connected to air contaminants in the ventilation system were rare at one in every 3,500,000 flights, [100] yet as late as 2009 advised that it was able to identify that 900 contaminated air events had occurred over 10 years to 2009. [101]

Oil seals that are acknowledged by design to potentially not be as efficient in certain stages of flight [14,15,16,17] may be seen as being an intermittent problem and part of normal [76,77] operations or a nuisance. [69,70] Many others in the aviation industry suggest contaminated air events are episodic or rare, including ASHRAE and the US Government funded ACER research group, [5,6] along with the former Director of the Aerospace Medical association recently stating fume events were *'very, very rare and very unusual.'* [101]

It therefore appears the interpretation of whether a fume event is seen as rare or not will depend on whether such events are referencing the occasional full oil seal failure, or the more frequent operation of oil seals that may leak smaller amounts at certain stages of operation and or due to the expected ongoing wear of the oil seals. Additionally, the use of the information for a selected purpose, including minimising the problem, actual understanding of the problem and the actual frequency of reports made via the varying reporting facilities, will also effect the interpretation of frequency. The reference to occasional maintenance problems (oil seal failure or similar), as distinct from acknowledgement to a basic design and operational issue of the way bleed air operates, is at the heart of the debate with the later rarely acknowledged as an issue. The minimisation of the regularity of events can only delay action or minimise concern.

6.4 How many events have been reported?

6.4.1 Initial collation of data

Although it is estimated that less than 4% of fume events are reported as required, a review of the data are available and which have been collated is important. [7,102] Table 6-1 provides data that was sourced by the author up until early 2004 and is simply meant to provide a snapshot of what is going on. This is the first collation of data known for contaminated air events and shows data that have remained not publicly available, or not collated or readily available.

Table 6-1: Rates of aircraft smoke/fume/oil and other fluid contamination as at January 2004

Taken from [7]

Type of report and country	Dates	Aircraft type	Number of reports	Comment	Source
BALPA - UK	2001	B757	1667+	1,667+ reports of smoke or fumes mostly thought to be from oil in air conditioning system	[1]
UK CAA MOR	1988-Jan 2004	B757	104+	"Smoke and or fumes" – oil/smoke/fumes/de-icing/hydraulic fluid • 16 reports 1988 – 1998 • 88 reports 1999 - January 2004	[103]
UK CAA MOR	1985-2003	BAe 146	85+	"Smoke and or fumes" – oil/smoke/fumes/de-icing/hydraulic fluid • 11 reports 1985 - 1995 • 68 reports 1996 - 2003	[103]
Other UK data	1998-2004	B757	47	Reports sent via email or airline reports (not on CAA data base)	[104]
Other UK data	2002-2004	BAe 146	23	Airline reports not on CAA data base	[104]

Type of report and country	Dates	Aircraft type	Number of reports	Comment	Source
CAA - UK	1989-1999	5 Jet types	128	Smoke/gas fumes (non-mandatory) • 1 event every 22,265 flights • B757 (21), BAe 146 (17)	[105, 106]
AAIB - UK	2000-2002	BAe 146 B757	19	Smoke/fumes incidents • B757 -10 • BAe 146 - 9+	[32]
BAE - UK	1985-2000	BAe 146	439	• 36 operators report 227 cases of contaminated air - 1985 - 2000 1 operator reports 212 cases of tainted cabin air in 1996 -1999	[107]
Aircraft Defect Reports - Australia	1991-1999	BAe 146	775	Mandatory reports in aircraft technical log. Number of reports • 1992: 418 reports = 1 in 66 flights • 1997: 189 • 1999 (6 months): 168 reports = 1 every 131 flights	[21]
Odour	1991-	BAe	791	Optional BAe 146 odour occurrence reports	[88]
CASA - Australia	1996-2002	BAe 146	22	Examples of oil seal bearing defects, fumes and crew impairment	[108]
ATSB - Australia	1991-2002	BAe 146	32	Oil/hydraulic fume - smoke or odour incidents	[109]
FAA - US	1986-2000	Various	8268	SDRS - Smell, fume, odour, gas, toxic fume, or toxic gas	[110]
AFA - US	1989-1998	MD80	760	900 reports at 1 airline - (73% on MD80)	[110]
FAA - US	1989-1999	Various	167	Accidents and Incidents Data Systems (AIDS) • 23 (14%) - Air quality events	[100]

Type of report and country	Dates	Aircraft type	Number of reports	Comment	Source
				connected to air contaminants in ventilation system – 1 every 3,590,000 departures • 60 events of ventilation toxic contaminant events + smoke in cockpit/cabin - (1978 - 1999)	
FAA - US	1992-2000	Various	4360	Fumes generated by engine/APU clearly present • Hazard level 0 to 2† • Events with no definitive cause not included • Less than 1 in 1,000 events were a serious threat to flight safety or immediate serious physical harm • Probability of smoke or fumes from propulsion system is less than 1 in 10,000 flights	[111]
NTSB - US	1990-2000	Jet	5	Smoke/fumes	[112]
TSB - Sweden	1999	BAe 146	1	All crew members 'temporarily effected by probably polluted cabin air'	[107]

† FAA - Hazard level 0: Consequences deemed to have no safety effect - fumes/smoke have no effect on crew or passenger beyond noticing them. Hazard level 2: significant consequences- smoke or toxic fumes that cause minor impairment or injuries to crew or passengers.

Table 6-1 must be reviewed in terms of acknowledging that only limited access to data was available, data has only been reviewed for selected aircraft types and under-reporting is a known problem.

In addition to the mandatory aircraft technical log reports for any aircraft defect coming to the pilot's attention, as previously noted, there are a number of additional defect or incident reports that are required to be made for fume events. However, in addition to the mandatory reports, there are a wide variety of additional reports that can be made on a non mandatory basis. These include airline and crew internal reports, reports sent to the manufacturer, manufacturer or regulator reports, union reports and many more. For such a heavily regulated industry, there is a surprising lack of conformity in the ways in which malfunctions and defects can be reported in the various national systems. [7]

Table 6-1 presents conflicting information, which will now be looked at in more detail. The data, while certainly by no means offering a complete picture, as they do not take into account the serious under-reporting problem, are however very significant. What the data do provide us with is that contaminated air events are not rare. This is simply a review of what's happening in several of the major countries for which access has been gained to at least some data. It should be stressed that the lack of information in a particular country does not indicate the problem is not occurring in that country; rather the information does not get collated.

One Australian airline Ansett, reported an oil/fumes event on its BAe 146 fleet every 66 flights in 1992, reducing to one every 131 flights in 1999 and 775 mandatory aircraft technical log reports in two and a half years. [21,61] With a fleet size of 13 to15 BAe 146 aircraft, operating perhaps 4 to 5 sectors per day, this equates to an event every day or two. There were another 791 *'BAe 146 cabin log odour occurrence'* optional fume reports made which were acknowledged as primarily Mobil Jet Oil II leaking into the air supply (of which 98% involved Ansett Australia). [88] However, the official *'Ansett BAe 146 Odour Inquiry Committee'* suspected that under-reporting was still continuing with the flight attendant union suggesting this could be up to 50%, despite crews advising that fumes were almost a normal occurrence and rarely reported. [88,113] While all events of suspected contaminated air are required to be reported to the aviation regulator, only 22 were passed on to CASA, according to its major defect web site. Therefore, the regulator by turning a blind eye could say fume events were very rare but the figures do not support this. CASA, based upon their awareness of 22 events, and seemingly oblivious to the figures that Ansett were reporting of 1 fume event occurring in every 131

(168 events in 6 months in 1999) flights, told the Australian Senate Inquiry that the aircraft had previously suffered from poor engine reliability, however now they considered the *‘the cabin environment of the BAe 146 aircraft is as chemically clean if not cleaner than other transport aircraft.’* [24] Ansett stated publicly that the drop in fume events from 1 every 66 flights in 1992 to one every 131 in 1999 was a *‘dramatic improvement.’* [21] To suggest a reduction of fume events from one event every day to one every 2 days was a dramatic improvement is inaccurate.

In an effort to suggest why Ansett was recording more fume events than other operators, it claimed that it was *‘different’* from other airlines in that it *‘required’* it’s crews to report all fume events. [21] This is inappropriate as all fume events are required to be reported globally, under-reporting was still suspected at Ansett and the failure of other airlines to report events must not be interpreted as events not taking place.

The available databases, other reports and documentation clearly show [61,88,114] the serious nature of fume events and the level of impairment taking place during these exposures. These involve clear descriptions of acknowledged oil fume defects, fumes occurring over numerous flights, a very high level of impairment with continuation of duty in an unsafe condition in many cases.

In the UK, the discrepancy in the figures can be seen in a survey of pilots showing that in excess of 1667 fume events, mostly attributed to oil fumes, that less than 4% of the events were reported as required and not sent through to the CAA. [1] This under reporting of UK events led to the CAA, based on the reports it actually collated, suggesting that smoke, gas or fume events occurred once in every 22,265 flights. [105,106] While Table 5.1 reveals that not all reports are being sent to the CAA, further review of the data available will show to what extent this is occurring. A well-known incident in the UK that resulted in *‘toxic fumes in the flight deck’* of a British Airways Boeing 757 resulted in the aircraft commander, Captain Hopkinson completing an Air Safety Report (ASR) about the incident after the event. [2] Captain Hopkinson who was subsequently medically retired, advised his airline that he wanted the ASR to be sent to the CAA. The report was never sent by the airline to the CAA. [115] The

Government then acknowledged the fume event had not been reported to the CAA at the time by the airline involved, due to an *'administrative oversight.'* [116] The Government response then suggested this was an example of the system working, as the crew had the right to contact the CAA directly about fume events, when in fact all MORs involving contaminated air events are required to be forwarded by the airline to the CAA, even if not requested to do so by the crew member.

Prior to the 2006 admission by the FAA that under-reporting was in fact occurring, the FAA stated that based upon one source of data (Accidents and Incidents Data System), there were only 23 air quality events connected to air contaminants in the ventilation system which amounted to 1 event approximately every 3.6 million departures. [100] The same database using a different search terminology found 60 events of ventilation contamination. However, a different data information collection system which is more commonly used, the Service Difficulty Reports System (SDRS), showed there were 8,268 cases of smells, fumes, toxic gases and similar. [110] Later FAA data shows 4,360 contaminated air events in an 8 year study or a probability of 1 event less than every 10,000 flights. [111] Even then, events with no definitive cause were not included and as it is often the case that events are not clearly identified, it could be assumed many fume events may be ignored, based on this alone. Interestingly, the FAA study stated that *'less than 1 per 1,000 events was considered a serious threat to health or flight safety.'* The FAA went on to state the definition of a *'serious threat to health and safety'* was, *'smoke/fumes resulting in serious impairment which included the loss of the crew's ability to see the flight deck instrumentation or perform expected duties.'* [111] To contrast the FAA figures, 1 major US airline reported 760 contaminated air events on the MD80 aircraft from 1989 to 1998. [110] This clearly casts doubt on the FAA sources of information.

Aircraft manufacturers can be another source of information, however the data are generally more difficult to obtain. British Aerospace, the manufacturer of the BAe 146, advised that it was aware of many contaminated air events on its aircraft. In fact, it advised awareness of 227 *'contaminated air events'* from 1985 to 2000 from 36 aircraft operators and 212 cases of *'tainted cabin air'* from just

1 operator from 1996 to 1999. [107] Given the problem of under-reporting, it is far more likely that the airline reporting the problem at a far higher rate was not an airline with a bigger problem, rather the problem will have been greatly under-reported by other airlines.

In 2008, Boeing acknowledged that over a 4 year period from 2004, operators had reported 43 cases of *'smoke/Burning odour'* to it as the manufacturer, related to engine oil over servicing, air supply contamination and the air cycle machine. [60] Boeing, at the same time, acknowledged that not all smoke/burning odour events were reported to it. [60]

The increase in the number of reports using the UK as an example, was most likely correctly assessed as being due to better reporting, [117] rather than the problem getting worse. This will be solely due to greater awareness by union activities, rather than the reporting system actually working as required. [118] Therefore, a further in-depth review of actual reported cabin fume events was seen as warranted. The author elected to undertake this in the UK purely given greater access to current information.

6.5 Case study: UK Contaminated Air Events Database (UKCAED)

Taken from [2] - See Appendix 1.

Based on the aviation industry commonly continued practice to downplay the frequency of contaminated air events, the author has undertaken a review of these reported events in the UK to determine the frequency of such incidents and related issues. This data will then be added to alternatively available fume events data to determine the extent of the problem and identify if industry positions on the frequency of contaminated air events are appropriate.

A collation of contaminated air events in the UK was drawn from a number of sources. Data were obtained and cross referenced from the CAA and AAIB databases, fume events submitted by crew to their airline or union or available through other sources such as direct from crews to non-governmental organisations (NGOs) such as AOPIS or to the author were merged to better understand the situation. The collated extensive data are attached and consist of 1050 contaminated air events reported in the UK from 1985 to mid 2006. Data were not actively collected in 2006, however events reviewed were received as a consequence of previous calls for data relating to contaminated air events from 2004/5 along with a CAA MOR database review in the second half of 2006. This is simply information collated by the author and in no way suggests that this is a complete list of all fume events that will have occurred. Reasons have already been cited why most contaminated air events will never be reported and further justification of this view and emerging trends will be analyzed and given upon review of the database.

An analysis of the database clearly shows that this is a significant body of data on contaminated air incidents that cannot be ignored without unbiased independent investigation.

The 2006 data are included to give a more complete picture, however it does distort the data somewhat as fume reports were not actively collated during this time and this factor must be taken into account. A number of the trends that stand out are listed below.

6.5.1 Number of contaminated air events increasing over the years

While taking into account that there is a slightly greater better awareness of the need to report fume events in the UK, due to a limited pilot union campaign encouraging their crews to report fume events between 2001 and 2005, before this time there was almost total non compliance with the reporting requirements. It is clear that the total number of contaminated events have been increasing over the years with 2005 being the year recording the highest number of events to date. The data in Table 6-2 show 2005 amounting to 25.2% of the total events recorded. The CAA has wavered frequently on its view regarding the trend in annual reported events. Between 2002 and 2005, the CAA and UK Government advised that the number of events were increasing [25,37,117] as well as decreasing. [119,120,121] In addition to the problem and denial of under-reporting which has gone unchecked for so many years, the Government stated that the events were not only decreasing in number but also in decreasing in *'seriousness.'* [121] There has been no check on the accuracy of Government assessments of the number of events occurring and Government figures provided are rarely challenged.

Table 6-2: Number of events reported per annum (UK CAED)

Taken from [2]

Year	Events	Year	Events	Year	Events	Year	Events
1985	2	1991	7	1997	13	2003	115
1986	0	1992	6	1998	10	2004	171
1987	1	1993	1	1999	27	2005	265
1988	2	1994	4	2000	49	2006†	90
1989	3	1995	0	2001	131		
1990	3	1996	9	2002	141	**TOTAL**	**1050**
†	In 2006; data were not actively collated and only up until July 2006						

It was estimated that based on the under-reporting factor of 3.66% and based on 72 CAA known fume event reports at the time, that up to 196,000 people (based on modest passenger load of 100) could have potentially been exposed to contaminated air in 2004. [122] These individuals could have presented themselves to their doctors with signs of acute toxicity, with no awareness of their exposure having taken place, as in almost all cases passengers are never informed when they have been exposed. [122] By applying the 3.66% under-reporting factor to the 265 number of known 2005 contaminated air events, this could equate to 7242 events or potentially (724,000) nearly three quarters of a million exposed passengers. [2] Again, almost none of these people would have been advised they had been exposed to contaminated air. While the captain has the discretion to inform passengers of a suspected fume event, they are not considered qualified to advise passengers what they may have been exposed to, [123] and advising passengers is not encouraged by the airlines.

The 3.66% reporting factor or almost 96% rate of under-reporting equates very closely to the recognised accepted defect product liability complaint rate of 3%. [124] This suggests that in the case of product defects, only 3% of the defects will actually be reported. However, some in aviation have suggested that in the aviation scenario, the reporting rate is most likely to be far lower. [125] This would be due to the reasons given for under-reporting as detailed in this chapter, the size of the global aviation industry and the uniqueness of the working environment found in the aviation industry for pilots and cabin crew.

6.5.2 All aircraft using bleed air report contaminated air events

It is clear from the database in Table 6-3 that certain aircraft types have significantly more reported contaminated air events than others. This is most likely due to technical and design problems, which are specific to these aircraft, types, specific maintenance issues and perhaps raised awareness due to union activities within certain airlines operating certain specific aircraft types. [118]

The Boeing 757 yields the greatest number of fume events at 42% of events, while the BAe 146 showed 22% of known events. The BAe 146 has an extensive history of ongoing contaminated air problems, which is clear to see from the extensive service bulletin and service information documentation which has been released by the manufacturer over the years since the BAe 146 entered airline service in the early 1980s. However, one of the major BAe 146 aircraft UK operators did not think fume events were reportable, as they did not affect safety. [2,55]

Table 6-3: UK Reported contaminated air events by aircraft type (UKCAED)

Taken from [2]

Type	Events	%	Type	Events	%
Airbus A300	1	0.09	Boeing 767	9	0.86
Airbus A319	48	4.57	Boeing 777	28	2.67
Airbus A320	65	6.19	Bombardier Dash 8	22	2.10
Airbus A321	7	0.67	Cessna CB560XL	1	0.09
Airbus A321	7	0.67	Concorde	3	0.29
Airbus A330	1	0.09	Dornier 328	2	0.19
Airbus A340	2	0.19	Douglas DC-10	1	0.09
ATR 42	1	0.09	Embraer 145	93	8.86
BAe 146/RJ	233	22.1	Fokker F70/F100	4	0.38
BAe ATP	16	1.53	Hawker HS125	1	0.09
Boeing 737	45	4.29	Lockheed L-188	1	0.09
Boeing 737	45	4.29	Saab 2000	2	0.19
Boeing 747	15	1.43	Saab 340	3	0.29
Boeing 757	444	42.29	Unknown Type	2	0.19
			TOTAL	**1050**	**100**

It must be remembered that this is a UK perspective and not all aircraft models are operated in the UK on the same scale as other countries. For instance, the McDonnell Douglas MD-80 has many reported events in the USA but in 2005 was not operated in the UK. Additionally, some aircraft types will be more widely used than other types and this needs to be taken into account when analysing these data. Importantly, these figures are a guide only as there may well be a greater awareness and willingness to report events within some B757 operators compared to the BAe 146 and other aircraft types. The greater reporting awareness on the UK B757 fleet is most likely due to specific union activities, [1,118] in addition to the fact the aircraft is one of the main identified problem aircraft. It should also be considered that some aircraft models like the Boeing 757 may use predominantly one engine manufacturer/model in one country compared to another country. In the UK all Boeing 757 reports relate to the Rolls-Royce RB211-535 engine.

By reviewing the events in the UKCAED, it is clearly possible to see that in the case of the BAe 146 for example, crews often refer to fume events as, *'not considered reportable under MOR scheme.'* Additionally, British Aerospace has acknowledged that this is a design issue in that the engine and APU oil seals *'May be less efficient during transients… or whilst the engine is still achieving an optimum operating temperature.'* [14,15] When combining these facts with the fact that some BAe 146 crews have advised that fumes are seen as a *'normal part of the operating environment'*, fumes were not viewed as affecting safety, [55] rather they were seen as a nuisance, [69,70] it can be assumed that the majority of BAe 146 events will never be reported.

Therefore, at best, the figures in Table 6-3 can only be seen as a guide showing that there is a problem of significant concern, particularly on certain aircraft types. Contaminated events can be assumed to occur on all aircraft types using bleed air to supply the cabin.

6.5.3 Events not being reported to the CAA

It can be seen from Table 6-4 that the percentage of contaminated air events being sent to the CAA as required, is decreasing over the years. During the years 1996-1999, while less contaminated air events were reported compared to the present, 80% were reported to the CAA. However, in 2005, of the 265 known events, only 127 were reported to the CAA, which amounted to 48% and not the 100% as required. In 2002, only 27% of known contaminated air events were reported to the CAA.

Interestingly, the percentage of aircraft types reporting contaminated air events to the CAA varied somewhat. While the average of all reporting to the CAA from 2002 to 2005 was 48% (same figure as the 2005 percentage), the known fume events reported to the CAA for the Dash 8, A319 and B757 varied between 33 and 38%. However, the EMB 145 and Boeing 747 show 83% and 80% of events being passed on to the CAA as required. The higher CAA awareness of these events on aircraft types reporting a smaller percentage of the overall figures is most likely linked to an increased proportion of events being reported on aircraft models which have less frequent events than on aircraft with more events where such events are seen as normal.

Table 6-4: Reporting Breakdown of Contaminated Air Events (UK CAED)

Taken from [2]

Year	1985-1995	1996-1999	2000	2001	2002	2003	2004	2005	2006 **
Total Events Reported	29	59	49	131	141	115	171	265	90
Events on CAA MOR database	29	47	26	91	37	55	86	127	54
Events not on CAA MOR database	*	12	23	40	104	60	85	138	36
% of events not on CAA MOR database		20.3	46.9	30.5	73.7	52.2	49.7	52.0	40.0
* Only data available were from the MOR database									
** In 2006; data were not actively collated and only up until July 2006									

The database provides many examples of why contaminated air events are not being reported as required. A few examples of these include:

- B757: *2 minute smell of oil on takeoff - oxygen not used and no Air Safety report (or MOR) as event not considered serious - part of continuing problem*;
- B757: *Hot oil smell on flight deck during takeoff run and for next 3 to 4 minutes. Smell lingered at low intensity for duration of flight. Fumes on previous sector as well were more pronounced but cleared rapidly within 2 minutes - Crew considered fumes as discomfort only (no MOR);*
- BAe 146: *Complete oil loss - smelt by several crews - Captain said ‘normal BAe 146 smell’ - First Officer ill still weeks later - Captain suffered effects later - 3 engine ferry next day - ASR filed (no MOR);*

- BAe 146: *No technical log entry - First Officer not feeling well on sector 4 of 4 sector day/Used Oxygen for last 15 minutes of flight - No odours or fumes present - However Symptoms were consistent with fume events and contaminated air on previous occasions - ASR Filed, Air Quality Report not filed, as there were NO FUMES detectable by smell - MOR filed but not on CAA database.*

As previously stated, the CAA has repeatedly refused to recognise that pilots are failing to report contaminated air events as required. [35,36,37] and has in fact taken great exception to being accused of ignoring it's duty for not accepting under-reporting. [38] The CAA advised that it undertook investigations into contaminated air events, after a *'small number of events'* were reported, by flight crew of fumes in the flight deck. [126] This view suggests that the CAA downplayed the significance of the problem, as the UKCAED and Table 5.4 do not show the number of events as *'small'*, particularly given the under-reporting factor.

Additionally the CAA and BALPA have allowed the 2007 COT inquiry to incorrectly advise that not only are air safety reports not required but that aircraft technical log reports are not required for contaminated air events. [39,53] The CAA has not corrected this despite the regulations requiring an aircraft technical log entry, an ASR and MOR report for all cases of suspected contaminated air events. [40,41,45,127]

There are several reasons why the CAA fails to view many contaminated air events as their concern. The CAA advised that many fume events were considered *'not safety related'* [128] and are *'lesser events'* for which the inclusion in the databases was not warranted and would not have advanced airworthiness or operational actions. [38] They suggested that many *'low level'* events had inconclusive connections to contaminated air and would not have improved safety by their inclusion. [119] In fact, the CAA suggested the inclusion of the *'large number of lesser events'* and *'subjective reports of a less serious nature'* would *'distort the picture'*. [38] The CAA even went as far as to say that their *'database contains hundreds of incidents involving smoke or fumes on flight decks and in cabins, by far the majority of which are considered* *insignificant incidents*.' [129] They then suggested their reporting system was so good that other countries were considering copying it. [130]

Given that the CAA has overtly acted contrary to the regulations and admissions that all contaminated air events must be reported, [40,41,42,43,44,45,127] it is little wonder that many airlines and aircrew see little reason to report events to the CAA or even report them at all. It can be seen from the examples given and throughout the database, that not only do many pilots see contaminated events as not reportable in the aircraft technical log or to the airline as an Air Safety Report, but the airlines are failing to pass the ASRs on to the CAA as MORs as required. The UK COT committee statement that, based upon its review of the UK database (UKCAED) compared to the CAA database, that '*after 2000 there is no evidence of major under reporting within the CAA database',* is very surprising, given that the under-reporting is self evident and undisputable. [131] However, the final COT report, while noting pilots stated under-reporting was widespread, stated it was not possible to determine the level of under-reporting, but still gave an estimate of how often fume events occurred. [39]

The data provided by the CAA on the number of contaminated air events have shown inconsistency and are clearly dependent on the collection method. As an example, the CAA advised it was aware of 10 BAe 146 fume events from January to December 2005. [132] However, the UK UKCAED database clearly shows 58 incidents on the BAe 146 aircraft of which the CAA is aware of 19, as these have MOR reference numbers attached to them. Therefore, the CAA was aware of only 17% of the known contaminated air events on the BAe 146 in 2005 and incorrectly advised Parliament that it knew of only 10 incidents when in fact it clearly knew of 19 events. The UKCAED database shows 385 contaminated air events from 1995 to October 2005, advised by the CAA as MOR reports, yet the CAA advised the House of Lords of only 280 events as shown in Table 6-5 during this period. [117] Table 6-5 shows that up until 2000, the CAA was aware of more contaminated air events than the author, however did not release these publicly. Since 2001, the CAA has publicly advised significantly less contaminated air MOR events than are listed on the UKCAED database, acknowledging only 35 events in 2005, despite 127 events relating to fumes being listed as MORs (indicating CAA awareness) in the UKCAED database.

Table 6-5: Comparison of contaminated air events: CAA MOR events on UKCAED database/CAA data provided to House of Lords

Year	1996 - 1999	2000	2001	2002	2003	2004	2005
CAA MOR events on UKCAED database	47	26	91	37	55	86	127
CAA MOR events advised by CAA to House of Lords [117]	63	35	52	27	29	36	35
Total events on UKCAED database	59	49	131	141	115	171	265
Pilot impairment events on UKCAED database	15	11	32	14	17	22	54
Pilot impairment events advised by CAA to House of Lords [117]	5	3	1	0	0	1	0

Another example involves the CAA advising the House of Commons in 2006 that there were 373 contaminated air events from 1 May 1996 to 30 April 2006, [133] yet the UKCAED database for the same period showed 1005 contaminated air events. Finally, the COT committee review of the UK database for a given period reported 262 contaminated air events, while the UKCAED database for the same period has 673 events. [2,37] The COT study attempted to estimate the actual number of smoke/fume incidents using a *'capture-recapture method'*, however this was later shown to be of limited value as both the CAA and UKCAED databases were recognised as incomplete. [39] Again, this does in no way take into account the under reporting problems which the CAA has continued to ignore, but the COT committee did acknowledge.

The fluctuating figures provided by the CAA have continued over the years. The Government advised an alternative set of contaminated air events on it's MOR database in 2007 as follows: 2002 (40); 2003 (35); 2004 (44); 2005 (78); 2006 (109). [134] These vary from not only the MOR events on the UKCAED database but also their own previously supplied figures to the House of Lords. [2,117] In 2007 and 2008, 116 and 97 contaminated air events were acknowledged by the CAA to have occurred, based on the MOR database. [135,136]

6.5.4 Crew impairment

There is no specific guidance requiring crews to report adverse health effects or partial impairment in the aircraft technical log, or through ASR or MOR forms. Incapacitation of the flight crew or incapacitation of the cabin crew rendering them unable to perform essential emergency duties or events requiring crew use of emergency oxygen are however listed as reportable via the MOR reporting scheme. [44] These reporting formats are aimed at primarily identifying aircraft malfunctions. Additionally, when for so many years crews have been informed that fumes are merely a nuisance with no adverse health effects, this simply reinforces the attitude that adverse symptoms are of nil importance or unrelated.

Table 6-6: Levels of crew impairment (UKCAED)

Taken from [2]

Year	**Total events reported**	**Pilot and/or Cabin crew adverse symptoms**		**1+ pilot impairment**		**2 pilot impairment**	
	Number	Number	%	Number	%	Number	%
1985 - 1995	29	2	7	0	0	0	0
1996 - 1999	59	25	42	15	25	11	19
2000	49	19	39	11	22	7	14
2001	131	50	38	32	24	20	15
2002	141	32	23	14	10	5	4
2003	115	41	36	17	15	7	6
2004	171	39	23	22	13	11	6
2005	265	84	32	54	20	24	9
2006†	90	29	32	29	32	8	9

† In 2006; data were not actively collated and only up until July 2006

After reviewing a 2004 version of the UKCAED database, the CAA stated that *'the number of events where impairment has been reported remains low.'* [117] By referring to Table 6-6, it is clearly evident that this statement is incorrect. Taking into account that adverse health effects in the form of impairment are not required to be documented and most events will never be reported at all, the level of impairment is considerable and clearly a flight safety issue.

Contaminated air events, in which pilots or cabin crew (aircrew) are reporting impairment, range from the more minor effects such as metallic taste, upper airway irritation or noxious/acrid odour right through to tingling, numbness, intoxication and full incapacitation. A close review of the attached UKCAED database will show that many events describe a significant degree of impairment up to more serious levels of impairment and cannot be dismissed as lesser events. However, where contaminants impair the performance of the aircrew to carry out their duties as required or cause undue discomfort or even transient adverse health effects in aircrew or passengers, this is a breach of the main airworthiness ventilation regulation, FAR 25.831/EASA CS 25.831 and other regulations. [7] While this may be acceptable in certain ground based occupations, in flight the aircrew must be expected to operate unimpaired so as to cope with any situation that might arise. The regulations clearly support this. The flight crews do not have the option of taking a break from their duties due to a distracting taste, headache or eye irritation and so on. To suggest that there are 2 pilots on board to cater for such situations is also flawed as these are multi crew operated aircraft and both pilots are required to be performing at peak efficiency and unimpaired to enable them to carry out their duties as operating crew members. Events of two-pilot incapacitation have occurred [2,32,107] as have cases of 2 pilot impairment. [2] Additionally, cabin crew are a key part of the safety envelope under which aircraft are operated in commercial service and they cannot be impaired or flight safety again will be compromised.

The first figure to examine in Table 6-6 is the overall level of crew impairment. In this case, the data refer to pilots and or cabin crew and in many cases it is not possible to determine which, as often not enough information is provided. In the earlier years of the database, there was a higher level of impairment such as 42% of crew reporting some degree of impairment in the years 1996 to 1999.

Over the 6.5 years of events from 2000 to mid 2006, 34% of contaminated air events showed some degree of aircrew impairment. In 2005 there were 84 cases of aircrew impairment reported out of the 265 reported fume events. This equates to 32% of the known reported contaminated air events in 2005 involving some form of aircrew impairment. [2]

While the reporting system is inadequate and generally does not provide data showing complete details of adverse effects, there are many events that specifically mention pilot impairment. Over the 6.5 years of events from 2000 to mid 2006, 21% (136 cases) of contaminated air events report impairment in varying degrees in at least 1 pilot. Over the same period, 10% (63 cases) of contaminated air events report impairment in varying degrees in both pilots. In 2005, there were 54 (20%) cases, of at least 1 pilot impairment of which 24 events (9%) noted that both pilots were adversely affected or impaired to varying degrees. [2] This figure will be in fact higher as the crew adverse effects figures will include pilots in many cases.

The CAA's view that the level of impairment remains low is demonstrated by the figures they provided Parliament shown in Table 6-5 suggesting that over the 11 years to 2005 there were only 10 cases of pilot impairment. [117] The UKCAED database shows that from 1995 to 2005 there were in fact 165 cases of at least 1 pilot being impaired and 85 cases of 2 pilots being impaired. In 2005 for example, the CAA advised there were no cases of pilot impairment while the UKCAED database shows there were 54 cases of at least 1 pilot being impaired and 24 cases of multi pilot impairment. Therefore, in addition to the CAA's inaccurate record of actual MOR events (127 on the UKCAED versus 35 advised to Parliament for 2005), and their refusal to look at the total number of events (265), has resulted in CAA grossly underestimating the number of cases of pilot impairment.

The CAA figures showing nil pilot impairment in 2005, while the UK database shows 54 and 24 cases of at least 1 or 2 pilots being impaired, respectively is very problematic. Impairments are any form of adverse reaction that does or could adversely affect the crew's performance. It could be that the CAA was referring to incapacitations and thereby downplaying the problem, however the database shows 8 cases of pilot partial or full incapacitations in 2005. The CAA was aware of all of these events, as they all have MOR reference numbers applied to them. There is no explanation for this other than an attempt to downplay the problem. Just 2 cases listing pilot impairment on the database include:

- B757: *Smelt 'fumes' on start up. Before takeoff P2 felt 'strange/vague' but then recovered and takeoff normal. In cruise no smells noticed but both crews felt nausea. No O2 used. Next day P1 Ok but P2 who had another exposure event on 20 September felt very fatigues, dizzy, nausea, vague, loss of balance. Following engine start, oil fumes were apparent on the flight deck. The fumes soon dissipated but, some minutes into flight, both flight crew suffered slight headache and mild nausea. All symptoms cleared by about 20 minutes after take off. The leaking oil had contaminated the APU;*
- BAe 146/RJ: *P2 illness/incapacitation possibly due to contamination of air conditioning system. On four consecutive training flights on three different fleet aircraft over a 9-day period, the P2 considered that the aircraft air conditioning systems might have been contaminated. Abnormal smells were reported and the P2 allegedly suffered with headaches, had difficulty concentrating and focusing with spots before the eyes, and on one occasion experienced severe vomiting. Medical assistance was sought. No other members of the crew were reportedly similarly affected. Following similar reports of flight deck/cabin smells maintenance requirements have now been upgraded…*

The CAA clearly states its duty of focusing on safety is on cases of slight impairment (able to perform duties with little difficulty but with reduced efficiency) through to full incapacitation. [97,137] However, the CAA views cases of crew feeling unwell during fume events such as headaches, nausea, eye, nose and irritation of the eyes, nose or throat which can occur with nil impairment are not part of its safety focus. [97,137] This definition clearly demonstrates why the CAA deems lesser events as outside its remit, however to suggest aircrew experiencing nausea, headaches or irritation does not fall under *‘slight impairment’* is inappropriate. Any adverse effect is a form of impairment to varying degrees and should not be disregarded by the CAA as a *'lesser event'*. The CAA also relies upon the very incomplete level of reporting of adverse health effects, and degree of impairment during fume exposures, to suggest that impairments remain low. The CAA remit states its *'primary safety focus'* is on cases from partial to full incapacitation, while slight impairment through to *'impairment'* falls under its *'safety focus'*. [97,137] Therefore, the CAA figures can be put down to, misuse of its definitions of impairment as well as errors in collating the data. Simple errors would have been amended over time given the level of evidence available and presented to the CAA, however this has not been the case.

Clearly the CAA's view that there were only 1 or 2 cases of impairment over the last few years is wrong, as Table 6-6 shows, the number of events of 1 or 2 pilot impairment is not low. The Government advised that *'very occasionally'* crews are exposed to leaking oil and *'occasionally feel ill'*, ranging from very mild effects through to irritation or more rarely partial incapacitation. [138] The UK COT committee likewise downplayed the significance of the UKCAED database level of impairment and adverse effects stating *'only a minority of the reports are associated with reports of adverse health effects'*, [131] despite an average of 34% of events showing some degree of impairment. [2] Cabin crew and passengers seem to be have been ignored almost totally.

Interestingly, the CAA advised that during the 11 year period from 1990, it had recorded 263 cases of smoke or fume events on 4 UK aircraft types with 25% of these involving crew or passenger discomfort such as nausea, sore throats or light headedness. [25] Clearly, the CAA does not view this as *'impairment'* and secondly, the UKCAED database shows only 129 suspected contaminated air events during this same period of which 94 were filed with the CAA as MORs. This highlights again the inaccuracy of the data provided to and used by the CAA.

6.5.5 Use of oxygen

Another significant trend to be drawn from the UKCAED database involves the failure of pilots to use oxygen during contaminated air events, despite the requirement to do so as shown in Table 6-7. [123,139]

The total number of cases where oxygen was reported to be used by one or more pilots or the user is unidentified from 1985 to 2006 is 174 cases, which equates to 16.6% of all cases. This is the maximum number of cases when oxygen was used, as oxygen is often only used by one pilot only and as the use of oxygen will more likely trigger an actual contaminated air report, the actual percentage of events where contaminated air is present and oxygen is used by both pilots will most likely be far lower. This is concerning when remembering that even the CAA have stated that oxygen should be used when the air is or suspected of being contaminated. Of the 265 contaminated air events in 2005, oxygen was used by 1 pilot in 11 cases (4%) and by both pilots in 25 (9%) cases.

Table 6-7: Pilot's use of oxygen during contaminated air events

	1985 to 1995	1996 to 1999	2000	2001	2002	2003	2004	2005	2006†
Number of reports	29	59	49	131	141	115	171	265	90
Oxygen used by 1 pilot	0	11	3	2	2	1	5	11	5
Oxygen used by 2 pilots	6	1	1	1	4	3	9	25	8
Oxygen used by unknown person (pilot/cabin crew)		3		10	8	19	22	14	
Oxygen used total	6	15	4	13	14	23	36	50	13
Maximum % oxygen use in all events	**20.7**	**25.4**	**8.2**	**9.9**	**9.9**	**20.0**	**21.1**	**18.9**	**14.4**

† In 2006; data were not actively collated and only up until July 2006

Despite the fact that the checklists require oxygen to be used in a contaminated air event, often it will be used temporarily only. The database itself shows that there is a great reluctance to use oxygen, and when it is used, often 1 pilot will optionally elect to use it, while the other pilot claims he or she does not require it or cannot detect the fumes. Often it is claimed the fumes came and went or there was not time to use oxygen. Other crews state that the fumes were so common that if there really was a problem they would be told about it and therefore oxygen was not necessary. Cabin crew are noted as occasionally using emergency cockpit oxygen or their own portable diluted oxygen. Some additional reasons given for pilots failing to use oxygen (O_2) as required include:

- *Did not use oxygen as advised by airline this meant declaring emergency and felt best not to do unless really violent effects from the smoke and that they were, 'used to bad smells on aircraft';*
- *Capt could barely detect smell or smoke and decided oxygen not required for crew or passengers;*
- *Unaware of need to use oxygen in all cases of contamination or suspected contamination;*

6.5.6 Multiple events recorded as one event

There are a significant number of reports that list fumes over several flights. Additionally, for reasons previously discussed, one recorded event will in fact refer to many occasions on which the fumes occurred whilst the crew operated the aircraft. Many pilots, contrary to the regulations, only report a fume event or selected defects on the last flight operated for the day so as to not delay the aircraft. [53]

The UKCAED database shows in Table 6-8 that from 1985 to 2006 there were a total of 135 repeat contaminated air events. This equates to an average of 13% of all events which are clearly repeat events, events in which aircraft are released for service following an event only to further experience further events. This will be the very minimum figure as this percentage does not include the significant number of events which are not reported and most MOR or non MOR reports would not contain any reference to maintenance action as they will be written prior to engineering action.

Some comments to support this include:

- *Engineering reported long history of fumes on fleet; Fault occurred on return sector or several sectors; Recurring fault; MEL already applied or* *cleared with fumes reported again; This is a frequent type of event on this fleet; P1 advised smelt perhaps 100 times on aircraft and part reason for leaving fleet; During consecutive sectors felt gradual deterioration in condition; Similar fault recorded under MEL 13 days earlier and cleared 3 days prior to this event.*

Table 6-8: Repeat events and engineering deficiencies

	1985 to 1995	1996 to 1999	2000	2001	2002	2003	2004	2005	2006†
Number of reports	29	59	49	131	141	115	171	265	90
Engineering No Fault Found	1	9	5	12	21	26	29	34	7
% of all events	3.4	15.3	10.2	9.2	14.9	22.6	17.0	12.8	7.8
Repeat events	0	14	10	23	13	15	19	32	9
% of all events	0.0	23.7	20.4	17.6	9.2	13.0	11.1	12.1	10.0
† In 2006; data were not actively collated and only up until July 2006									

Additionally, an average minimum of 14% of all events are events in which engineering report no fault found or were unable to find a fault in the allocated time to do so. Time available for maintenance can often be as little as 30 minutes if an aircraft is needed for a further service and engineering are under pressure to release the aircraft for further service. This highlights many serious engineering and maintenance practice flaws that are allowing these events to continue. Some of these include:

- Engineers look at aircraft, report *'no fault found'* and send aircraft back into service or often ask crews to *'report further'*. Further events occur with subsequent more thorough investigation finding oil leaks;
- Aircraft sent flying with MEL applied with further fume events reported;
- Aircraft signed off as report further;

- Engineers not always willing to investigate or able to investigate thoroughly;
- Source difficult to find: *'Crew could not find source or isolate/no fault found'*;
- No maintenance action taken after fume events with aircraft returned to service with further problems occurring;
- Pilots advise engineering of fume events verbally only;
- Fumes reported in tech log *'for info only'* (for information only).

The problems of engineering often not able to find faults related to contaminated air upon initial or further inspection are not uncommon with the difficulties noted in locating the source of the fault well noted [90] and serious consequences in some cases clearly evident. [140]

A few actual examples showing this include:

- A320: *Oil smell on flight deck after takeoff, and during climb to 12,000 feet. Fumes not considered intense enough to warrant use of oxygen. (Further flight same day) Fumes on previous sector - engineers signed off as 'report further', no fault found - fumes again same day - strong musty oil fumes gave P1 immediate intense headache and crew were hospitalised - Event was traced to the APU which was scheduled to be replaced;*
- B757: *Transient fumes on takeoff (QRH not done as transient). Fumes returned later with pilots getting eye - nose and throat irritation. Engineers reluctantly investigated and found hydraulic leak. MEL'd with one pack off. Fumes returned on return flight;*

6.5.7 Events not recorded in aircraft technical log and not considered reportable

It can also be seen that reports are often not being reported in the aircraft technical log as required by the aircraft captain. Comments to support this include:

- *Events generally not recorded on previous flights with fumes except occasional tech log entry; Fumes on 2nd sector with 2 cabin crew on oxygen as dizzy and light headed - Aircraft continued to operate with P1 dizzy and tingling in legs on 4th sector. Nothing entered in tech log (no MOR); Fumes not written in tech log as P2 could not detect fumes; "Normal BAe 146 smell"; The incident was reported over the phone to an engineer. Not written up; P2 said fumes and smoke was nothing to worry about and not really a problem; Smoke/fumes in cabin. No Tech Log entry made - unable to investigate. CAA Closure: No further action possible; Strong fumes smell on change from APU to Eng air after T/O. P2 later had headache, dry eyes, tingling, arms and legs. Not considered reportable under MOR scheme and no tech log entry made by crew therefore no engineering investigation.*

The view that events are not reportable is clearly occuring at airline management level and is recognised by the CAA [55] and therefore explains why have incorrectly adopted this viewpoint.

6.5.8 Crew errors being made

Another trend emerging from the contaminated air events database is that crews are making errors, sometimes directly attributed to air contamination, while others are not so clear. Some examples include:

- BAe 146: *'Capt, First Officer and cabin crew unwell making small errors (slow to put gear down)';*
- B757: *'Oily smell on outbound sector. On return sector crew unaware that they were becoming partially incapacitated. P1 then forgot to slow aircraft. Numerous ATC calls were missed, prompting ATC to ask aircraft if everything was all right. P1 then forgot to slow a/c during approach until reminded to do so at 3.7d (miles). Crew unaware that they were becoming partially incapacitated';*
- BAe 146: *'Flight crew experienced similar symptoms yet no fumes present. Errors made: Took off in wrong flap setting even though P2 had mentioned they had symptoms of contaminated air and that both should be more alert. No ASR or air quality report filed as no fumes or odors*

present. Same P2 on 17, 19, 20 and 25 Aug, 2004 on same aircraft with symptoms present on all days.'

There is an average of 12% (124 events) of all contaminated air events in which crews reported adverse health effects but failed to report these as an MOR event, with 22% (229 events) of all contaminated air events in which crews reported adverse health effects resulting in an MOR being reported. Combining events, which were not recorded as MOR events, with all known MOR events, shows an average of 34% of events resulting in some form of declared adverse health effect. Accepting the reporting rate of 3.66% of all events, this could equate to 460 events per year in the UK, where crews were experiencing some form of adverse health effect due to contaminated air. 34% is a statistically concerning figure. The AAIB report into a British Airways Boeing 757 diversion into London Gatwick airport due to a technical issue which also subsequently resulted in fumes in the cockpit and aircraft control difficulties highlighted the need to use oxygen:

- *'The flight crew had made a positive decision to action the emergency checklist and don their oxygen masks in a timely manner. This was a prudent course of action, given that experience shows that pilot's well-being and judgment can be affected by exposure to engine oil fumes. Had they not taken this action, the subsequent handling difficulties on the final approach to London Gatwick could have been further compounded, increasing the degree of risk.'* [141]

6.5.9 Crews continue flight duties

Throughout the database there are many examples of crews continuing duty after experiencing contaminated air with or without a variety of symptoms. This is contrary to the regulations and should not be occurring. Some examples include:

- B757: *'Captain and two cabin crew reported light headed, headaches and burning noses. Airline medical department cleared crew for return sector. Engineering found no obvious oil leaks and suspected defect may be linked to high oil consumption in right engine which had a history of this';*

- A320: *'Oily fumes in flight deck. Aircraft had history of smoke and fumes on previous 2 sectors in tech log with engineers requesting new crew to report further. Engine recently changed. Crew tasted and smelt oil fumes. Passengers reported fumes in cabin. P1 - light headed, dry mouth, tired, tightening around eyes and felt pressure to continue duty. P1 requested blood tests from airline medical department but advised not possible and A&E also unlikely to do these. Requested airline medical doctor to follow up and advised that blood test not available as no base line done and exposed to too low a concentration';*
- BAe 146: *'Fumes on 2nd sector with 2 cabin crew on oxygen as dizzy and light headed. Aircraft continued to operate with P1 dizzy and tingling in legs on 4th sector. Nothing entered in tech log. ASR and air quality report to be filed.'*

6.5.10 AAIB investigations

The UKCAED database also shows that between 1985 and 1995 no events were investigated by the AAIB. However, there are 60 references of AAIB reviews or investigations from 1996 to 2005 with a drop off in numbers investigated as the years have gone on. As noted previously, the UK Government advised in 2006 that only 23 events had been investigated since 1996. [142] However, it is difficult to be precise on the number of events of which the AAIB are aware as they have released few reports publicly. The UKCAED database shows that 27 contaminated air events which state '*AAIB provided CAA with initial notification'*. This again shows that the CAA reporting system is not working as required as the crews or the airline should have provided the CAA with its initial notification.

6.5.11 Other consequences of contaminated air

An area most often over looked is or includes the consequences of contaminated air events. These include the actioning of a number of emergency procedures, return to land or return to the terminal, priority landings, fire service in attendance, emergency evacuations (including injuries) or disembarkations and similar. Over the 21 year period there were 153 PAN or mayday emergency calls or cases where the aircraft fire services attended, 105 cases of the aircraft returning to base or being diverted and 30 cases of passenger evacuation or disembarkation. Not surprisingly, these have also increased over the years with 2005 once again recording the highest number of events to date.

6.5.12 Passengers

It is very apparent from the UKCAED database that passenger effects are rarely reported. This is certainly due to the fact they are never told that a contaminated air event might have taken place and they will remain unaware of why they might feel unwell after a flight if the flight has adversely affected them. As the reports are usually prepared by the crew on the aircraft before disembarking, they will never capture any medical effects that present themselves after the crew or passengers have left the aircraft unless a new report was submitted. This results in all medical effects for both crews and passengers usually never being properly recorded. It should be further noted that the delayed onset of effects will further complicate the collation of important exposure data in passengers.

6.5.13 Regulator actions are inappropriate

By reviewing the CAA MOR events in the UKCAED database, a common theme is the CAA comment in response to such contaminated air events. Comments recorded by the CAA *'The hazard is acceptable provided the frequency remains low.'* Other CAA comments include '*The hazard is adequately controlled by the action stated above'* and after a report which included all of the following *'Smoke/fumes in cabin. No Tech Log entry made. Unable to investigate'*, the CAA responded with *'CAA Closure: No further action possible.'*

In isolation one incident on a particular aircraft may not seem of importance to the regulator and there may not be an extensive number of reported contaminated air events being submitted to regulators. However, by reviewing the number of events on an aircraft type generally, the problem as a whole within aviation, the obvious failings shown in the databases and acknowledging the failure in the reporting system in general, it is clear the number of events occurring is neither low nor rare. To suggest so is inappropriate use of the information presented and a failure to recognize that aviation rules and regulations clearly do not allow for contaminated air. The failings within the UK system are not isolated to the UK regulator, as the pattern has been also seen in Australia and other countries.

6.5.14 Reasons for crew under reporting

There are many clear reasons given for crews failing to report contaminated air events. A limited selection of the typical reasons given by crews for not reporting contaminated air events in the aircraft log or maintenance log as required include but are not limited to: [2,7,61,102]

- Fumes considered transient or intermittent;
- Fumes are seen as comfort or health issue only and not related to aircraft safety;
- Long history of fumes/known fault;
- No fault found repeatedly quoted by engineers;
- Regularly smell dirty socks/smells seen as normal;
- Crews advised there are no health concerns or that their symptoms must be due to something else;
- Fumes not considered reportable – such as an Air Safety Report (ASR) or as an Mandatory Occurrence Report (MOR) under the mandatory reporting scheme, or as a 'Major Defect';
- Not all crews smelt fumes;
- Other pilot advises nothing to worry about and fumes are not a problem;
- Intimidation from airline managers;
- Job security problems and reluctance to be seen as trouble makers;
- Unaware of level of contamination;
- Less aware of fumes as time went by so assumed contamination had cleared rather than realizing the crew had been desensitised to the smells;
- Incident reported by previous crew or on previous sectors but felt pressure to continue flying despite problem still present;

- Wasting time writing reports as engineers are most often not fixing the problems;
- Don’t want to have the aircraft grounded;
- When asked by the flight attendants, the pilots refused to write up fume events;
- Crew awareness that some crews have been intimidated, stood down, terminated or lost medical licenses after reporting fumes;
- Fumes are considered a nuisance only, more normal than not;
- If fumes were reported every time smelt, aircraft would be grounded very often.

6.6 Other sources of data

6.6.1 British Airways

British Airways (BA) over time has supplied data relating to contaminated air events numbers to various different bodies, organizations and individuals. These range from individual crew members and unions to Government bodies. The data supplied have come in various formats ranging from graphs to numerical format, often differing numbers are provided and the data provided is done in a manner that does not clearly reveal the total number of pilot technical log reports (PIREP) or technical log reports occurring. In 2006, British Airways advised the UK COT committee about the number of oil fume reports it held on its Boeing 757 database. [143,144] A careful review of this previously unavailable information is shown in Table 6-9 and it reveals some significant data. The engines referenced are the Rolls-Royce RB 211-535C and E4.

From 1999 to 2005 the airline had received 1446 B757 PIREP reports on oil fumes. [143,145] The data presented graphically to the UK COT Committee showed that between 95 and 516 PIREP oil fume reports were received per year, however neither the written submission of the BA report or the COT analysis highlighted that in fact there were in excess of 1400 oil fume reports logged by BA pilots over the six year period to 2005. [143,144,146]

British Airways data stated there were only 197 ASR *'fume reports'* from 2002 to 2005, yet acknowledges (graphically) there were 430 PIREP oil fume reports for the same period, this indicates a 46% conversion rate from oil fume PIREP report to ASR, despite all *'smoke, toxic or noxious fumes'* reports occurring and necessitating an ASR to be raised according to the airline itself. [46,143] Different BA data indicate there were only 81 *'British Airways confirmed'* contaminated *'air supply report'* ASR reports for the period 2002-2005 which would be a lower PIREP to ASR conversion rate of only 19%. The ASR reporting rate of oil fume reports was even lower in 2000/2001 at just 8% during the period in which the airline had a higher number of Boeing 757 in the fleet powered by the 535C engine which only BA operated, a consequence of being one of the two launch customers for the original B757 535C powered aircraft.

This engine variant aircraft was progressively phased out (many sold to DHL) by BA between 2001 and early 2003.

Table 6-9: Boeing 757 - British Airways

Source	1999	2000	2001	2002	2003	2004	2005	TOTAL
# PIREP oil fume reports: 535C & E4 engine [143]	330	170	516	119	95	113	103	1446
# PIREP oil fume reports: 535C & E4 engine [143]				119	95	113	103	430
# PIREP oil fume reports: 535C & E4 engine [143]	330	170	516	119	95			1230
# PIREP oil smell reports 535 E4 engine [147]	99	36	131	76	80			422
Calculated PIREP oil smell reports 535C engine 1999-2003 [143,147]								808
UKCAED 535C and 535 E4 fume reports [2]	2	7	48	30	41	33	37	238* BA=225
# PIREP Cabin odour powerplant implicated reports – 535C [147] Jan 2000 – Feb 2004								500
# PIREP Cabin odour powerplant implicated reports 535 E4 [147] Jan 2000 – Feb 2004								280
Calculated PIREP oil smell reports 535 E4 [147] Jan 2000 – Feb 2004		36	131	76	80	17**		340
ASR: Confirmed contaminated air supply by engine or APU: 'Fume event' (Graphical) 2002 - 2005 [143]				29	33	26	29	117
ASR: Confirmed				16	26	21	18	81

Source	1999	2000	2001	2002	2003	2004	2005	TOTAL
contaminated air supply by engine or APU: ‘Total air supply reports’ (Graphical) 2002-2005 [143]								(89) ***
ASR: Confirmed contaminated air supply by engine or APU: ‘Confirmed engine/APU defect’ (Graphical) 2002-2005 [143]				8	11	11	10	40
ASR: Confirmed contaminated air supply by engine or APU: Fume event. Written statement [143] 2002-2005				X	X	X	X	197
Oil fume PIREP reports per 100 sectors (maximum) 535 C and E4 [143,146]								0.64% (< 1%)
Oil fume ASR reports per 100 sectors (maximum) 535C and E4 [143,146]								0.09%
Sectors flown per year [146]								19000
Rate of oil fume reports based on average 19000 sectors per year with 1446 oil fume PIREP reports: 1999-2005								1%
Average annual confirmed engine/APU defect from ASR 2000-2005 (2001 – 30) [143,146]								10

Source	1999	2000	2001	2002	2003	2004	2005	TOTAL
Potential for smoke/fumes ASRs related to oil/hydraulic contamination confirmed by engineering [146]								0.05%
2 Pilots report oil fume ASRs [143,146]								68
PIREP engine/APU change [143]	20	23	37	10	6	5	4	105
PIREP engine/APU change/confirmed defect [143]	11	8	6	4	2	3	-	34

* Includes 40 de-identified B757 reports. 2/3 of these assumed to be BA B757 aircraft = 27 (238-13=225)

** Jan/Feb 2004: assumed: 13 reports

*** 89 dependent on how the ASR data provided were supplied

The UKCAED database during the same period (1999-2005) shows 238 Boeing 757 contaminated air reports of which all but 40 are identified as being BA aircraft. Assuming 2/3 of the de-identified B757 reports are BA reports (author documented that pilots in other B757 operated airlines were overall less likely to report events, with a few crews reporting extensively) at best, the UKCAED has 225 BA Boeing 757 fume reports during this period. This indicates the UKCAED database contains only 15% (225 out of 1446) of the BA B757 contaminated air events known to BA. [2,143,145]

Another source of data presented by BA to the CAA and BALPA in 2004 was listed as *'confidential'* and involves a 2004 BA summary of *'oil smell'* PIREP reports on the B757 using the Rolls Royce RB11-535E4 engine. [147] The data revealed there were 422 oil fume pilot reports between 1999 and 2003 on the B757 using the 535 E4 engine. 1230 BA oil fume PIREP reports for the same period were provided to the COT committee on both engine types operated on the B757 (RB211 535C and 535E4). [143,145] This would indicate therefore that there were approximately 808 oil fume pilot reports on the B757 aircraft using the 535C engine between 1999 and 2003. [143,147]

The data presented confidentially in 2004 indicate that there were approximately 500 and 280 *'powerplant implicated cabin odour pilot reports'* between January 2000 and February 2004 on the Boeing 757 535C and 535E4 powered fleets, respectively. [147] The A 319 IAE and A320 CFM powered engines show the next highest number of engine-implicated odour pilot reports during the same period at 150 with 8 other aircraft types reporting approximately 195 reports in total. The B757 cabin odour pilot reports represent 69% of the total reports during this period with the A319/A320 aircraft representing 15%. [147]

While approximately 340 oil fume pilot reports were filed between 2000 and February 2004 for the 535 E4 engine on the B757, approximately 280 or 82% of the oil fume reports implicated the powerplant, according to the data supplied. [147]

Of the 81 ASRs between 2002 and 2005 related to air supply issues, BA advised that there were an average of 10 confirmed engine or APU defects per year related to contaminated air. [143,146] However, the graphical PIREP data provide the level of confirmed engine or APU defects related to oil fumes only after engine or APU changes were undertaken and do not provide data on confirmed defects that did not necessitate an engine or APU change. The airline is therefore under-reporting the number of confirmed events by stating that only 10 engine or APU defects were related to contaminated air. The airline has not quantified what is meant by *'confirmed engine or APU defects per year related to contaminated air'* and neither has the airline declared how many times engineering requested pilots to report further before taking action, or how many events were linked to delayed or inadequate engineering maintenance practices. As such, this selective provision of data is of limited value.

The COT committee and UK Government uncritically accepted that based on approximately 19000 sectors per year on the B757, 10 confirmed oil fume defects based on ASR reports alone correlated to 0.05% rate (1 in 2000 flights) of confirmed oil fume defects. [36,146] Detailed analysis of the PIREP charts indicates that, based on 19000 sectors per annum, there was a 0.03% rate of engine or APU change with a 0.01% rate of confirmed defects based on the engine/APU change. [143,146] However, these figures do not provide data on confirmed defects where an engine/APU was not removed. Neither do the data reflect that many defects would be rectified during scheduled engine maintenance and overhaul or events, which occurred due to oil over servicing. Consequently, the BA data number will be a significant underestimate. Data on the number of confirmed oil related defects based on all PIREP reports were not provided, [143] which is of course the main data that would be required for a thorough analysis. Additionally, this does not take into account the recognised difficulty in identifying oil related defects.

Based on the PIREP oil fume reports between 1999 and 2005, there was a 1% rate of reporting oil fume events, based on sectors flown, while it was 0.5% between 2002 and 2005. The COT committee supplied maximum rate of oil fume reports was 0.64% (average of 0.37%) [143,146] and was the basis of the COT statement that oil fumes are reported in 1% of flights. This is in addition presumably to the number of PIREP reports, which compared to the total sectors over the 7 year period which also reported a 1% frequency of events. Based on the number of reports of oil fumes, in addition to the engine changes, a number of work packages, oil level servicing procedures and modifications related to the *'front end'* bearings were undertaken. [147] These considerations indicate that the reports were not baseless and provide justification for requiring publications of the total number of defects found based on the total reports (PIREP) filed by pilots.

The UKCAED data clearly show that engineering is often not finding the source of the reported problem upon initial investigation, fumes are often ongoing and upon initial investigation crews are asked to report further. The difficulties faced in positively identifying the source of contamination, is well documented, [2,7,30,90,140,148] with residual oil contamination and ongoing leaks with associated reports not uncommon. These issues do not even take into account the under-reporting problem in the first place. Therefore, the BA evidence, while not complete, is uncommonly detailed, unverified, not cross referenced independently with the actual internal documentation and whilst important, cannot be used as a accurate basis for determining the reporting rate of oil fumes or defects found. It certainly shows that of the events reported by the pilots, few are being further reported as an ASR to the airline or an MOR to the CAA. As such, this is clear evidence that the reporting system is not working.

In a similar manner to DHL advising its pilots that transient oil fumes at a certain stage of operation were not required to be reported, [76,77] BA provides evidence of the same thinking on oil fumes. [147] While all toxic or noxious fumes are required to be reported as an aircraft defect, ASR and MOR, [41,42,43,44,45,46,127] internal previously unseen records [147] show that the BA policy on reporting contaminated air events was that guidance to crews was such that no report is required when the fumes are of *'such short duration that a report is not considered necessary by the crew'* in which no action would be taken (level 0). A cabin odour report via the flight crew report (FCR) would be recorded (level 1) when a transient aircraft related fume event with no physiological effect takes place at a level that needs to be reported to enable a record of the event and monitoring to take place so as to identify a trend to enable early action. The third level of report (level 2) logged in the aircraft maintenance log (AML/technical log) is used for a transient aircraft related fume event, with no physiological effect, requiring some engineering action in the short term but at a *'level such that a higher level of reporting is considered essential by the crew.'* In this case, engineering will monitor the reports with some sort of short-term action taking place to identify the cause, resolve the problem and prevent a more significant problem. BA stated that an ASR was only required (level 3) if the fumes had an *'adverse implication on aircraft safety'*, if the fume event is not transient, immediate short term engineering action is required and if the fumes event is of a level that *'requires the crew to use oxygen, action the QRH,* (Quick reference handling procedures) *or results in physiological effects.'*

This hierarchy of reporting requirements shows that the determination of what is considered a contaminated air defect is subjective, based on the pilots understanding of the event. While the regulations and Government statements are generally clear that all suspected contaminated air events have to be reported, the reality is that the pilots, airline and regulators have very different views. All defects that are drawn to the commander's notice should to be reported in the aircraft technical log. It should therefore not be open for interpretation of what level of noxious fume event has occurred and left to the interpretation of the reporter, given the varying levels of understanding of what this might be for different individuals. British Airways advises clearly that only a fume event that jeopardises flight safety (has an adverse impact on aircraft safety) is a mandatory *'reportable incident.'* [46,143,147] While the airline might suggest that many events may not fall into the category of having *'an adverse implication with regard to aircraft safety'* or that *'smoke, toxic or noxious fumes'* fall outside the ASR/MOR reporting mandatory requirement, [143,147] this is incorrect as once again the regulations are clear, even within the internal airline guidelines. All suspected contaminated air events, smoke, toxic or noxious fume incidents must be reported [41,42,43,44,45,46,127] rather than the use of the airline categorization of reporting requirements. [147]

While BA, in a similar manner to many other airlines, suggested that there was an open reporting culture in their airline and all events are investigated and reporting is encouraged, [144,149] this statement needs closer review. The UKCAED database and other documents reported here and elsewhere [1,7] clearly demonstrate that crews are in many cases reluctant to report fume events for a variety of reasons. One clear example of pressure placed on crew was demonstrated when BA advised the COT committee in 2006 that 2 of it's B757 pilots were responsible for 34.5% (68 out of 197) of the ASRs submitted on fume events on the B757 fleet from 2002 – 2005. [143,146] The airline stated it had no idea why these 2 pilots were reporting at a higher level than other crews [143] and that it had no evidence of health problems related to contaminated air. [149] The pilots in question, both captains, are known to the author. One being medically retired by the airline due to documented contaminated air exposures with TCP found in the blood (with removal of medical certificate by CAA based on contaminated air medical reports) aged 44. The other died from brain cancer in early 2009 whilst still in his 40s. [150,151] Brain cancer has being linked to neurotoxin exposure in recent studies. [152,153] Both pilots had repeatedly spoken out and reported their concerns about fume events, yet they were singled out by the airline for raising more reports than the other pilots with the airline not accepting their concerns. This issue along with the airline subjective interpretations (DHL/BA) of what needs to be reported, even though contrary to the regulations, suggests there is a clear clash between crew impairment, health effects, the evidence to support such concerns and airline operations. One of the captains in question, who was deemed to over report fume events and was subsequently medically retired, reported a fume event in 2005 in the aircraft technical log which was subsequently signed off as *'info noted - please report further'*, indicating the aircraft was cleared to fly again. [154] Pilots subsequently reported the fumes reoccurred two days later.

6.6.2 DHL and Flybe

Flybe advised the UK COT committee that in 2002/3 only 0.02% of sectors reported a confirmed oil or hydraulic smoke/fume report (16 out of 56504 sectors) with only 1 fault found, 14 ASRs and 2 MORs. [146,155] Flybe also stated that in 9 months to September 2006, 0.05% of sectors reported a confirmed fume report (35 out of 74966 sectors) with 12 faults found.

DHL advised that in 2004 that its fleet of Boeing 757 aircraft (purchased from BA with RB 211 535C engine) had no confirmed oil fume events, in 2005 it stated there were 4 confirmed air conditioning defects which represented <0.02% of sectors (17830) and in 10 months to October 2006 there were 22 confirmed ASR reports of oil fumes where a defect was confirmed or 0.15% of sectors. [146,156] DHL advised it was company policy for an ASR and the aircraft tech log to be completed when fume events were *'reported'* so that the company could investigate and determine possible causes, however only a minority (66% in 2005; 23% in 2006) would be sent to the CAA as MORs. The decision on whether to report an event was deemed subjective. There was no record of how many oil fume reports were raised by pilots in total, rather only confirmation of defects. Again, the limited ratio of defects confirmed to reports made does not indicate that the events are not occurring, rather it highlights the problems in the maintenance systems identifying oil fumes.

Based on the data supplied by 3 UK airlines (BA, FlyBe, DHL), the COT committee advised that oil fume reports were likely to be reported in 1% of flights, while confirmed defects related to contaminated air events were likely to happen at a rate of 0.05%. Clearly the 1% figure came from the BA supplied data, while the 0.05% figure came from all 3 airlines.

It is only via a careful review of the internal aircraft technical log reports, other internal reporting systems and maintenance databases that an accurate picture could be obtained, however these data has never been made available. Even if the data had been made available providing reported fume events, the figures given would not take into account the under-reporting factor. A quick reference of the UKCAED database shows some of the information supplied by at least 2 of the airlines examined by COT is inaccurate. For example, BA has reported that in 2005 there were no confirmed defects based on engine or APU changes, yet the UKCAED database, despite not having a full record of the event, shows there were in fact at least 9 confirmed defects linked to contaminated air, at least 5 cases of oil over servicing leading to fumes and 1 confirmed engine/APU change/defect. The UKCAED database during 2002/3 contains 22 Flybe fume events, of which 7 were submitted as MORs, 2 registered with the AAIB and one requiring the fire services. The UKCAED database shows strong evidence that within Flybe, fume events were not seen as reportable under the MOR scheme, evidence of no technical log entry being made after some events and repeatedly no fault being found by engineering. The fact that Flybe did not see contaminated air events as reportable since they did not consider fume events affected safety is clearly known to the manufacturer and CAA. [55]

The under-reporting problem, endorsed in reality by the airlines and regulator, is another ongoing issue on top of the inaccurate use of information available to the airlines. The data available on the UKCAED database shows, where DHL Boeing 757 aircraft are identifiable, that the only data available are 6 events reported between 2005 and 2006. In all cases, fumes were evident, as well as crew impairment and even hospitalization (1 without MOR), however only 4 of these were sent to the CAA as an MOR. The same aircraft were previously owned by BA and recorded 22 fume events on the UKCAED during 2000/01, yet upon handover to DHL no events were reported on the database. This most likely indicates a poor culture of reporting events within DHL, which is supported by the DHL view that transient fume events at certain stages of operation are normal and not to be reported. [76]

6.6.3 UK MOR Database 2009

In addition to the previous search undertaken on the UK CAA Mandatory Occurrence Reporting (MOR) databases (see Table 5-1 and the UKCAED database) in relation to contaminated air events, a further search was undertaken from 01 January 2009 to 31 July 2009 for aircraft above 40,000 kg. As such, aircraft such as the Dash 8 will not have been part of this review, yet are known to incur numerous fume events.

In the first 7 months of 2009 there were a minimum of 41 MOR reports (the exact number cannot be confirmed due to an inconsistency in the data being supplied by the CAA) equating to over 70 events per annum. This compares to 91 in 2001, 37 in 2002, 55 in 2003 and 97 in 2008. [136]

Of the 41 events in the first part of 2009, the Boeing 757 accounted for 29% of events followed by the Airbus A320 on 17%, the Boeing 737 and Airbus A319 both on 15% and the Boeing 777 on 10% of events. The BAe 146 had reduced to 2% of events as the aircraft was replaced with a newer type by one of the principal UK BAe 146 operators, FlyBe.

The data continue to show the clear trend of over 90% of crew not using emergency oxygen during contaminated air events; a reporting system not working and an ongoing complete complacency of the aviation regulator to resolve the ongoing contaminated air problems. These trends are typified in a Boeing 757 incident of 17 February 2009. The CAA MOR summary states:

- *During a full power take-off a strong oil smell was noted by all occupants. When flaps were retracted problem was traced to LH air conditioning pack, which was turned off for remainder of flight. F/O on jump seat confirmed that same smell had been detected a couple of days previously although no record made in Tech Log. Both flight crew noted that their throats felt sore and were 'coated' in something and P2's pre-existing headache was considerably worse. Passing about 15000ft on descent smell was noted emanating from the other pack and F/O on jump seat complained of a tingling sensation in his arms and donned his oxygen mask until just before touchdown.*

- *CAA Closure: These reports are a known problem with this airframe/engine installation. The operator has introduced a series of maintenance actions to be carried when these events occur. They continue to review each report and work closely with both the airframe and engine manufacturers to try and reduce the problem. After investigation and troubleshooting, no further smells were apparent.*

The review of the database for 2009 indicates that the problem remains ongoing with little change to address the problem. The UK Government failure to highlight that fume events require an MOR report to be raised, while the use of oxygen and emergency procedures did, is an example how the Government/CAA indirectly avoids recognition that all cases of *'smoke or toxic or noxious fumes'* are required to be reported under the MOR scheme. [43,44,157]

6.6.4 USA

Little data are available from the US for public review regarding contaminated air events, despite such events being required to be reported in a variety of ways including in the aircraft technical log, via the FAA service difficulty reporting scheme (SDR) and the Accident and Incident Data System (AIDS). [158] This is supported by the FAAs recognition in 2006 that crews and airlines are under-reporting smoke and fume events. [66,67] Additional sources of data include the voluntary Aviation Safety Reporting System (ASRS) [159,160] and union collated fume events. [110,161]

A recent rigorous analysis of contaminated air events (focus was on oil, but cursory search for hydraulic fumes included) was undertaken by two labor union representatives over an 18 month period from January 2006. [158] 470 incidents were found in a search of the SDRS, AIDS, airline reports copied by cabin crew to their labor union and media clips with only strongly associated events included. On average 0.86 oil or hydraulic fluids associated events were reported per day. 74% of the events were recorded in one or more of the FAA databases searched, 24% were reported by the cabin crew to their airline and 8% reported to the media, with overlapping reporting formats occuring. A total of 47 aircraft types were cited with the aircraft most commonly reporting events being: CL 600 (11%), DC9 (11%), MD80 (9%); ERJ 145 (8%), B737 (6%) and

B757 (6%). 68% were reported in flight only with 42% of these reported during the climb. 57% of the flights were diverted to another airport with 6% reporting aborted take offs or emergency landings. 25% of the events occurred on the ground only with the majority occurring during taxi in or out, with a majority returning to the gate and reported as delayed or cancelled.

Despite the same national reporting requirements, the differing approach to reporting amongst airlines was clearly demonstrated as shown in Table 6-10. [158]

Table 6-10: US airline reporting comparison

	Airline A	Airline B
Total number of flights reported	33	55
Total reports supplied in writing by cabin crew to airline	25	53
Total reports sent by airline to FAA	13	3
Total reports not sent by airline to FAA	20	52
Total reports supplied to media	4	4
Total reports not sent to the FAA by airline (which clearly met the FAA SDR reporting requirements) – In flight	5 (all diverted)	6 (all with smoke and 4 diverted)
Total reports not sent to the FAA† by airline (which clearly met the FAA SDR reporting requirements) – Ground	5 (smoke and returned to gate or never left gate)	14 (smoke and returned to gate or never left gate)
Number and percentage of reports that met SDR not reported to FAA by airline	**10 out of 33** **30%**	**14 out of 52** **27%**
† SDR - Not required to be sent to FAA as ground operations		

While the above table has a bias towards cabin crew supplied data to their airline, with similar pilot data not available, the data show that almost one third of reports required to be sent to the FAA were not. There are no data to show the extent to which pilots are reporting events in the aircraft technical log, however, given that all defects must be recorded in the aircraft log and 60% of events at Airline A and 95% of events at Airline B are not reported to the FAA, it is assumed there ought to be a considerable events recorded in the aircraft technical log, however the author feels this is unlikely to be the case.

In 2002, the US National Research Council (NRC) published estimations of frequency of air supply contamination with engine oil or hydraulic fluid for a small selection of aircraft types in 3 airlines over several years. [162,163] Per 1000 flight sectors, it was estimated that fume events occurred at a rate of 3.88 for the BAe 146 (6.4/year); 1.29 for the A320 (1.67/year); 1.25 for the B747 (0.34/year); 1.04 for the DC10 (0.38/year); 1.02 for the MD80, 0.63 for the B767 (0.21/year), and 0.09 for the B737 (0.07/year). Given an estimated 10,556,000 departures on U.S. airlines in 2006 by applying the lowest frequency estimate of 0.09 events per 1000 flight cycles fleet-wide, for example, translates into 950 events per year in the U.S. fleet or an average of 2.6 events each day. [158] Using an average of 0.88 (excluding BAe 146) events per 1000 sectors, this would equate to 9289 events per year on the US fleet or 25 per day. However, based on extensive data collated by the author, these figures seem unrealistically low and part of the under-reporting culture.

A US Flight Safety Foundation representative estimated that 5-10 aircraft are diverted per day around the world due to smoke, fume or fire events, with most being smoke based on briefings received from manufacturers, FAA, NTSB, US and international airlines. [164] However, this was still thought to represent *'only a portion of the actual number.'* The FAA had previously estimated smoke diversions in the US to be around 1 flight per day. [165]

The fact that the above study supports that 57% of the events reported in flight resulted in flight diversions and the majority of ground based events resulted in delayed or cancelled flights, these data suggests there is a business case for improved maintenance systems, the implementation of sensor technology to detect events at an earlier stage and air cleaning or filtration systems. [158]

Collation of fume events from databases, including the FAA, flight attendant reports and the media will underestimate the number of events for several reasons. [158] These include: limited access to FAA databases through searches are likely incomplete due to difficulty in search methodology; airlines under-report events to FAA; limited access to flight attendant reports; flight attendants under-report events to their airlines and pilot reports, apart from the limited FAA records, are not accessible. However, the review undertaken in 2008, [158] highlights a number of common themes also found by the author. A number of such factors include that: often smoke/fume events are not identified by maintenance till later, with the source of the problem not being fixed; without detection systems to help identify the cause, maintenance may take too long to identify the problem or fail to identify it; reliance on crew noses as the only sensors, the description of the smell may be misidentified (e.g. described as electrical when in fact found to be oil); SDR reports do not generally describe adverse crew or passenger effects. The difficulty in identifying the source of oil fumes has been acknowledged by many including Boeing, Lufthansa and Honeywell. [60,90,166]

The FAA, despite saying in 2006 that under-reporting was occurring and not all fume events were being sent to the FAA, [66,67] then stated in 2009, when discussing the frequency of such events, that over 10 years (to 2009) it had recorded 900 fume events on its database. [101] Quite clearly, selective use of information is often used to control the subject matter. Boeing advised in 2010 that based on the US FAA AIDS and SDRS databases, bleed air contamination incidents were very low at 2.7 events per 1,000,000 departures. [94] These data appear to correlate with the 2002 FAA fume event frequency analysis, [100] however they do not take into account the more recent FAA recognition that under-reporting is occuring. [66,67]

6.6.4.1 Germany

In 2009, the German Parliament advised that the German aviation regulator, the Luftfahrt-Bundesamt **(**LBA), had advised it had received 156 fume incident events since 2004. [167] However, just one operator, Eurowings operating a fleet of 15 BAe 146 aircraft over a 16 month period from October 2007 to January 2009, recorded at least 158 fume events with a breakdown as shown in Table 6-11. [168]

Table 6-11: Eurowings contaminated air events

Fume events	158	2.4/week
Smell reported	151	96%
Symptoms reported	18	11%
Oil/Engine/APU fault found	69	44%
Other causes identified	8	5%
Oxygen used	3	1.9%

Given that the LBA advised it had 156 contaminated air events in total over 5 years, these BAe 146 data (158 events) provide evidence that fume events are not being reported to the LBA and BFU (Bundesstelle für Flugunfalluntersuchung) as required under the German legislation.

Events were reported on all 15 aircraft within the Eurowings BAe 146 fleet, ranging from 5-20 reports per aircraft, with the average being 11 reports per aircraft. Additionally, these data show fume events are not rare, the source of the fault is often not found and that oxygen is virtually never used. One event in September 2008 reports cabin crew with severe adverse symptoms (cough, difficulty breathing and feeling unwell), yet with no toxic smell reported. The BAe required Inspection Service Bulletins (ISB) were carried out, finding the *'oil leak at APU compressor.'*

This supports the fact that in many cases crews report the same adverse pattern of symptoms without noticing the actual fumes. The actions taken by the airline ranged from performing run ups or inspections often with no fault found, through to the more thorough procedures required under the mandatory BAe ISBs 21-150 and 21-156 which were more likely to find the defects. The database provides evidence that maintenance is very often not finding the faults, with the aircraft sent back out as serviceable or accepted for flight with items inoperative and therefore in accordance with the MEL system, resulting in events continuing to be reported on later flights. This example provides evidence that in addition to intermittent oil fumes, [30] not all crews are reporting fume events as required as the contaminated air continues, yet were not reported, sometimes for several sectors/days. The data from Eurowings provide a very comprehensive view on how contaminated air events are dealt with within an airline.

Two typical examples from the German database that highlight the problems with engineering fault finding are shown in Table 6-12 and Table 6-13, which look closely at two specific aircraft registrations. [168]

In aircraft A, shown in Table 6-12, it appears the aircraft flew for 5 months with an APU that was leaking before a work order (W.O) was raised to address the problem. Furthermore, the entry on 20 July 2008 by one crew, referring to comments by another crew who clearly did not report the contaminated air officially but chose to simply inform the next crew once more, shows a reporting system that is clearly failing to work.

Table 6-12: Aircraft A: D-AEWO

Date and Location	Crew report	Maintenance Action
20/02/2008 Frankfurt	'Acid smell in cockpit/air and ground with APU air selected on, coming from both packs.'	'Inspected outlet ducts of both packs, found no oil contamination. Set APU air inop.'
2008		APU use was re-instated (date unknown)
11/4/2008 Nuremburg	'While selected pack no 2 on, smell in cabin and cockpit.'	'Performed inspection, found contamination in APU bay (de-icing fluid). Cleaned APU bay. Run up tests with APU air reveal oil small, boroscope reveal compressor shaft seal leak set APU air inop.'
2008		APU re-instated (date unknown)
20/07/2008 Frankfurt	'Previous crew (both pilots + 1 cabin crew) reported strong strange smell on flight deck and forward part of cabin with APU and pack no 2 on assuringly toxic oil smell.'	'Performed SB21-150 and SB21-156 Rev. Oct 2002 found slight oil seepage at APU compressor and shaft seal, mixed with dirt. No findings on all engines and packs and ducts. Opened follow W.O 449886.'

In aircraft B, it took maintenance over two months to actually fix the problem (see Table 6-13). Initially with 2 reports over 3 days, no fault was identified on each occasion. With reports continuing over the next few days, initially the APU was suspected and placed as inoperative, with the engine identified as having an oil leak with the report the following day and subsequently the engine was replaced.

A week later, the APU was placed as inoperative again after a fume report and a problem was identified with the APU, however 2 days later, a further oil leak was found in the APU which led to the APU being changed. A report was made implicating the APU just 2 days later, yet inspection found no fault and a week later after further reports a leak was found in engines 2 and 3. No data were supplied on what action took place. However, 2 weeks later a similar report was made and on this occasion a leak was found in engine 3, which was subsequently replaced.

Table 6-13: Aircraft B: D-AJET

Date and Location	Crew report	Maintenance Action
13/10/07 Dusseldorf	'Cabin attendants complain about burning eyes with Pack 2 on.'	'Performed run-up; no findings.'
16/10/07 Dusseldorf	'Same problem; bad small on flight deck with burning eyes and metallic taste.'	'Inspected ducts no findings; air cycle machine pack 2 abnormal noise and smell, set pack 2 inop; replaced air cycle machine.'
18/11/07 Frankfurt	'Foul oil small in cabin mid section extreme and cockpit also acrid smell.'	'Performed inspection; no oil contamination found but still smell from APU air, set APU air inoperative.'
19/11/07 Frankfurt	'Oil smell in cockpit (packs used with engine air only).'	'Performed inspection, found small oil leak in engine number 2 (bearing 2), engine changed.'
26/11/07 Dusseldorf	'Acrid smell reported by CA2L in the aft galley.'	'Performed inspection, found APU combustor drain blocked. Set APU air inoperative. Run-up performed; APU drain changed.'

Date and Location	Crew report	Maintenance Action
28/11/07 Dusseldorf	‘Smell on flight deck: smell similar to old socks with pack 1 and 2 on. When selecting pack 1 to off smell disappeared: According to CAB crew no smell noticed; continuation of flight to DUS with pack off. No physical effect on cockpit crew.’	'Performed inspection, found APU oil leak; changed APU.'
30/11/07 NUE	‘Smell on flight deck and in cabin from APU with pack #2 confirmed by 3 of 4 crewmembers.’	'Performed inspection, and runup; no findings.’
7/12/07 Dusseldorf	‘After air bleed change during departure an exhaust gas type smell was noticed on the flight deck mixed with sour note also noticed in cabin by proceeding crew as well as passengers.’	'Performed inspection, found engine # 2 and 3 oil contamination.'
21/12/07 Dusseldorf	‘Strong smell (like exhaust gas or burned oil) after air bleed change from APU air to engine air in the cockpit and 1L station. Rear cabin OK. After shutting down pack #1, air quality OK.’	'Performed inspection, found engine # 3 oil leak; replaced engine.'
28/12/07 BLQ	‘Bad smell in forward part of aircraft. After switching off pack 1 smell disappeared.’	'Performed inspection, found pack # 1 dirty; set inop; pack changed.’

Again, a week later after further reports, the number 1 pack was found dirty and changed. This is one of the very rare times we get to see the clear attitude towards and failure to rectify an ongoing maintenance problem.

In summary, these two examples demonstrate how maintenance personnel are failing to properly fault find reported contaminated air events. If aircraft had accurate detection systems fitted in the engine bleed air ducts, their task would be so much easier to carry out and this would improve flight safety and decrease the number of those being exposed. The same theme can be seen throughout all the databases the author has reviewed, even though the level varies. Bleed air monitoring systems have been called for by a growing number of authoritive bodies, however, to date the call has been ignored. [5,61,148,162,169,170]

Other reports from Germany, which involved suspected contaminated air events and were confirmed and cross-checked by the media outlet ARD/WDR included 200 events over a 25 month period up until February 2010. [171] The events were broken into the following categories: BAe 146 – 113; BAe 146RJ – 11; Boeing767 - 7; Boeing757 – 56; Boeing747 – 1; Boeing737 – 1; Airbus A319 – 3; Airbus A340 – 6; CL600 /CL70 – 2. It was noted that the tabulated events *'may not constitute any conclusions as to the number of actual numbers of events with the airlines listed.'*

6.6.5 Holland

An aircraft maintenance log for a KLM Cityhopper Fokker 100 PH-OFL aircraft between 2 October 2008 and 15 April 2009 reported 16 contaminated air events. [172] Descriptions of the contaminated air included:

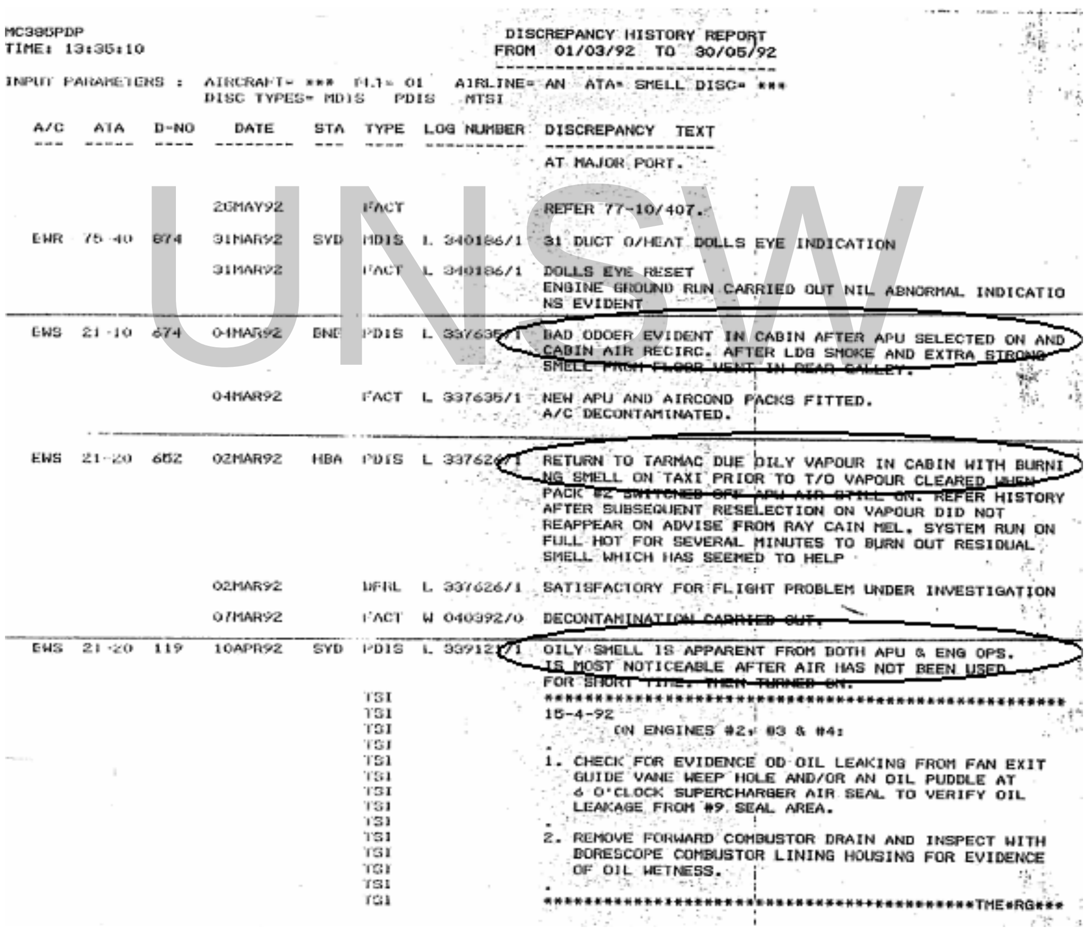
- *'During idle descent very strong wetsock smell';*
- *'Unacceptable wet socks smell emanating into the galley and fwd and mid passenger compartment. Some passengers complaining';*
- *'unacceptable wet socks smell in cockpit and cabin.'*

In all cases the smell was described as *'wet socks'*, and while engineering work was in some cases extensive, fume reports continued. On one particular day (21/1/09), the wet socks smell was reported, with a response given noting *'already on DDL'*, (deferred defect list) indicating that maintenance was aware of the report and had released the aircraft for further service. A further report of *'unacceptable wet socks'* was reported by the pilots with the response that the defect was to be transferred to the deferred defect list until the end of the flying day, indicating that the aircraft could continue flying for the remainder of the day. One further report by the pilots the same day noted the wet sock smell in the cabin and cockpit. Numerous defects were found over the period including hydraulic fluid leakage; blue waste fluid leakage as well as replacement of the air cycle machine, coalessor bags and left hand pack.

6.6.6 Ansett Australia

While contaminated air events predominantly related to oil leakage are well documented, a recent review of a previously unavailable database, involving fume events on Ansett Australia's BAe 146 fleet between 1992 and 1994 is of considerable interest. [173] The documents were obtained as part of legal proceedings in the courts, which enabled 3 folders (339 pages) of discrepancy reports, used by the airline-engineering department, to be reviewed. 3828 discrepancy reports were reviewed (1660 in 1992, 1093 in 1993 and 1075 in 1994). Figure 6-1 shows a sample of the discrepancy reports and Figure 6-2 shows an analysis of this data.

Figure 6-1: Sample Ansett discrepancy reports



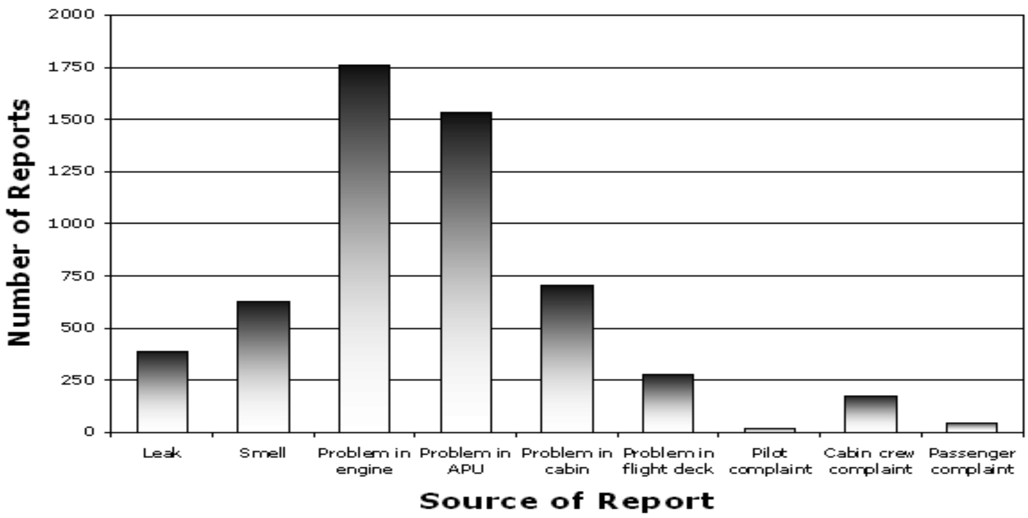
MC385PDP
TIME: 13:35:10

DISCREPANCY HISTORY REPORT
FROM 01/03/92 TO 30/05/92

INPUT PARAMETERS : AIRCRAFT= *** FLT= 01 AIRLINE= AN ATA= SMELL DISC= ***
DISC TYPES= MDIS PDIS MTSI

A/C	ATA	D-NO	DATE	STA	TYPE	LOG NUMBER	DISCREPANCY TEXT
							AT MAJOR PORT.
			26MAY92		FACT		REFER 77-10/407.
EWR	75-40	674	31MAR92	SYD	MDIS	L 340186/1	31 DUCT O/HEAT DOLLS EYE INDICATION
			31MAR92		FACT	L 340186/1	DOLLS EYE RESET ENGINE GROUND RUN CARRIED OUT NIL ABNORMAL INDICATIONS EVIDENT
EWS	21-10	674	04MAR92	BNE	PDIS	L 337635/1	BAD ODOER EVIDENT IN CABIN AFTER APU SELECTED ON AND CABIN AIR RECIRC. AFTER LDG SMOKE AND EXTRA STRONG SMELL FROM FLOOR VENT IN REAR GALLEY.
			04MAR92		FACT	L 337635/1	NEW APU AND AIRCOND PACKS FITTED. A/C DECONTAMINATED.
EWS	21-20	652	02MAR92	HBA	PDIS	L 337626/1	RETURN TO TARMAC DUE OILY VAPOUR IN CABIN WITH BURNING SMELL ON TAXI PRIOR TO T/O VAPOUR CLEARED WHEN PACK #2 SWITCHED OFF APU AIR STILL ON. REFER HISTORY AFTER SUBSEQUENT RESELECTION ON VAPOUR DID NOT REAPPEAR ON ADVISE FROM RAY CAIN MEL. SYSTEM RUN ON FULL HOT FOR SEVERAL MINUTES TO BURN OUT RESIDUAL SMELL WHICH HAS SEEMED TO HELP
			02MAR92		WFRL	L 337626/1	SATISFACTORY FOR FLIGHT PROBLEM UNDER INVESTIGATION
			07MAR92		FACT	W 040392/0	DECONTAMINATION CARRIED OUT.
EWS	21-20	119	10APR92	SYD	PDIS	L 339121/1	OILY SMELL IS APPARENT FROM BOTH APU & ENG OPS. IS MOST NOTICEABLE AFTER AIR HAS NOT BEEN USED FOR SHORT TIME. THEN TURNED ON.
					TSI		**
					TSI		15-4-92
					TSI		ON ENGINES #2, #3 & #4:
					TSI		.
					TSI		1. CHECK FOR EVIDENCE OD OIL LEAKING FROM FAN EXIT
					TSI		GUIDE VANE WEEP HOLE AND/OR AN OIL PUDDLE AT
					TSI		6 O'CLOCK SUPERCHARGER AIR SEAL TO VERIFY OIL
					TSI		LEAKAGE FROM #9 SEAL AREA.
					TSI		.
					TSI		2. REMOVE FORWARD COMBUSTOR DRAIN AND INSPECT WITH
					TSI		BORESCOPE COMBUSTOR LINING HOUSING FOR EVIDENCE
					TSI		OF OIL WETNESS.
					TSI		.
					TSI		***TME*RG***

Figure 6-2: 1992 - 1994 Ansett Discrepancy Reports by source of problem



Additionally the records in Figure 6-2 show the source of the problem varied with most attributed to the engine (1762 reports) followed closely by the APU (1530 reports). Description and therefore the source of the events varied somewhat with overlap evident.

While there was a perception in Ansett that the oil leak problem only involved the BAe 146-300 series, the data clearly show that all aircraft were affected, as were all models of the BAe 146 operated in Ansett.

Examples of the discrepancies include:

- *'Strong smell from aircon system noticed by aircrew and flight attendants on last part of descent and on and after landing. Nil operational impact. RH pack burn out carried out. Nil evidence of oil smell';*
- *'For info: oily smell from APU air whenever used. Noted. APU air not to be used. To be investigated at comp conv. Checked for leaks, nil found. Extensive ground run carried out. Nil smells evident';*
- *'Oily smell in cockpit from APU air, only very slight smell in cabin. Pack burn out carried out. APU cooling fan inspected nil oil evident. Report further if necessary.'*

Further analysis of the data shows there were 544 incidents which state there were *'oil smells'* or *'smoke/fumes/haze in the cockpit'* in the report or that oil smells were reported and an oil leak was found on inspection. A further 122 reports state there were *‘APU smells*’, *‘A/C smells’*, *‘146 smell’*, *‘Acrid smells’* or *‘Foul smells’*.

There are another 150 reports which contain technical summaries relating to oil contamination problems such as *‘A/C contamination’*, *‘Engine leaking oil’*, *‘APU cooling fan leaking/sooting ‘* and such like.

The data include other information which is also of interest:

- Aircraft registered EWJ required oil *‘topping up’* of 720ml in 4 days and then a further 5.6 litres of oil top ups over the next 23 days;
- One report claims breathing problems in crew and that the APU cooling shroud seals are broken and letting ASBESTOS into the airstream;
- There were 14 reports about oil smells and fumes to aircraft registered JJY in May/June/July 1993, before any action/inspected was carried out;
- One report highlights how a cabin crew member had to go on to oxygen for 30 minutes due to oil smoke in cabin, experiencing difficulty breathing and heart palpitations;
- Repeated comments of *‘Nil time for further investigation.’*

6.6.7 National Transport Safety Bureaus

Australian Transport Safety Bureau (ATSB) Database Analysis

A review of the ATSB database using the word *‘smoke’* and *‘fumes’* as the key search terms was carried out in late 2009.

Key search term: ‘Smoke’

A search of the database using the key word *‘smoke’*, for the period 28 February 1990 to 13 October 2009, provided 661 events. Of these 124 events (18.8%) were or might be related to the contamination of the cabin air from engine oils or hydraulic fluids. All events reported to be smoke from an identified source such as smoking in toilets, cargo smoke, oven, galley smoke or electrical smoke, were discounted.

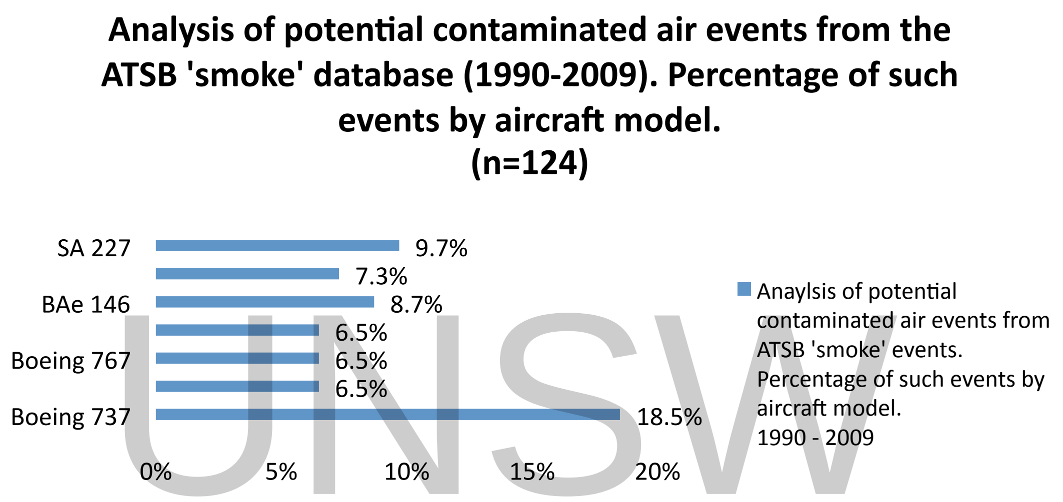
The database provided came in a table format with data available in a number of formats such as ATSB reference number, occurrence date, location of the event, aircraft type and model and so forth. The data also included an ATSB

Summary of the event, which varied significantly in detail. Events may be summarised in two sentences such as:

- *'While en route, the crew declared a PAN due to smoke in the cockpit. Emergency services were activated for the aircraft's arrival. The aircraft landed safely.'* [174]

The highest occurrences per aircraft model are shown in Figure 6-3.

Figure 6-3: Percentage of 'smoke' events related to cabin air contamination by aircraft model



Some events were reported in a more detailed manner, such as the following Boeing 767 event:

- *'During the right engine start procedure, the cabin of a B767 filled with acrid smoke. The cabin crew reported that the smoke was increasing, and the engine was shutdown. The bleed air was removed and all the electrical busses were depowered. Although the smoke had reduced, it had penetrated all areas of the cabin. An evacuation of the passenger cabin through the aerobridge was considered most appropriate. However, evacuation was delayed due to the shearing of a tow bar pin. The situation was reassessed, as the smoke was clearing. The original decision to evacuate via the aerobridge was again considered to be the most appropriate action, and subsequently, a slow and controlled emergency evacuation was carried out. Supplemental oxygen was* *administered to a small number of passengers in the terminal. All passengers were reported to have recovered.*' [175]

Key search term: 'Fumes'

A review of the ATSB database using *'fumes'* as the key search term, for the period 29 January 1990 to October 2009, provided 593 events. Of these 211 (35.6%) were or were most probably related to events where the air supply became contaminated by engine oils or hydraulic fluids. Additional events may be also linked to engine oils or hydraulic fluids, but due to the fact the ATSB summary often lacks more than the basic details of an event, these could not be confirmed and were therefore excluded from the above mentioned 211 events.

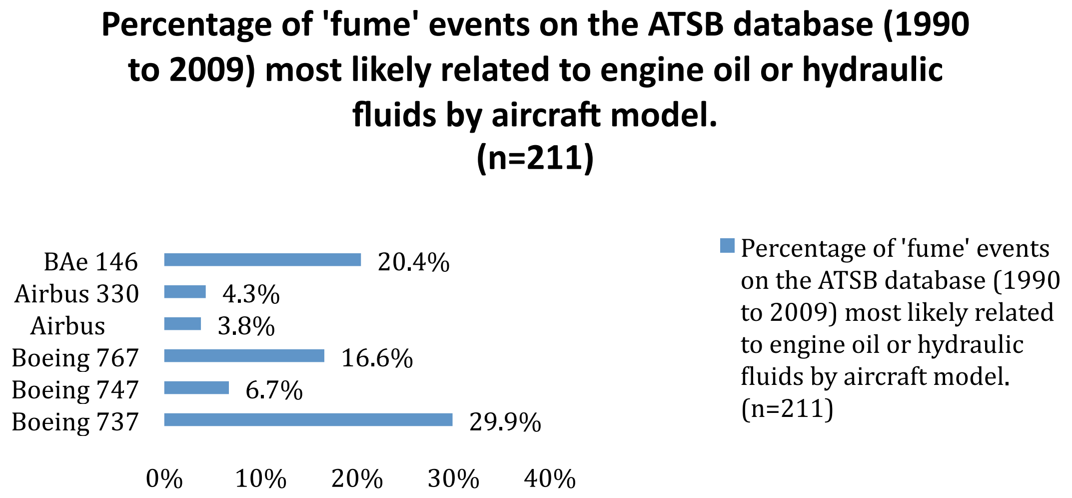
The database raises a number of interesting points. The first listed BAe 146 incident on the database occurred on 7 July 1995 and the ATSB summary is as follows:

- *'After landing a complaint was made that five passengers and one cabin attendant had become ill after being affected by fumes from the airconditioning system. This is a known problem with this type of aircraft when an engine oil seal allows oil to enter the airconditioning system. The fumes are non-toxic but have a noxious odour. Normal maintenance practices were unable to find the source of the smell therefore the number 3 engine was replaced.' [176]*

The comment that the *'fumes are non-toxic'* on an aircraft with no form of detection system to measure the chemicals or their concentrations is interesting and underestimates the significance of the event with the comment having no technical value. BAe 146 events were still occurring in 2008 showing a failure of the manufacturer to provide a robust technical solution to problems highlighted ever since the aircraft first flew commercially in 1983.

Of the 211 fume events the following six aircraft models accounted for over 81.5% of all reported such events as shown in Figure 6-4.

Figure 6-4: ‘Fume’ events for six highest reporting models



The database shows that as of June 2009, even very new aircraft models such as the Embraer ERJ 190 (which first flew in 2004), were experiencing contaminated air events:

- *‘Shortly after takeoff, a 'strong gaseous oil smell' was noticed on the flight deck and in the forward cabin. The smell dissipated after about 10 minutes but as the aircraft passed through 7,000 ft during descent, the smell returned. Several passengers reported headache and feelings of nausea.’* [177]

Due to the lack of detail in the ATSB summary, proper analysis is difficult. However of note is that only 25 (11.8%) of the 211 *‘fume’* events resulted in one or more pilots using emergency oxygen. Events where the crew even report mild irritation of the eyes, throat and nose still did not trigger crew oxygen use. This safety failing has also been shown to be prevalent in other countries such as the United Kingdom.

The fact the ATSB database has no other BAe 146 *‘fume’* events listed prior to 1995 highlights a significant potential pitfall in those accessing the ATSB or any other safety authority database to investigate any potential safety trends for statistical purposes. In evidence to the Australian Senate investigation of 1999-2000, [61] the ATSB provided a number of examples of what it called were *‘Fume/Smoke/Odour’* related occurrences from 1991 to 1999. The ATSB BAe

146 data included an event on aircraft registered VH-EWJ on 5 August 1992 which stated:

- *'After take-off, the engine bleed air was switched on and an unpleasant smell was evident in the cockpit. One cabin attendant placed on oxygen. APU oil seal leaked oil into the air conditioning system.'* [178]

Three other significant BAe 146 oil related contaminated air events that were not included on the 1990-2009 ATSB smoke/fumes database provide evidence that the database searches are not accurate. These incidents include the 1992 and 1993 events reported in successful legal proceedings and a 1997 fume event that resulted in the captain no longer able to fly or retain medical certification. [179,180,181, 182]

A request to the ATSB from the investigative reporter Ross Coulthart in early 2009 for data relating to *'smoke and fume events'* from 01 April 2007 to 31 March 2009 resulted in the ATSB advising there were 132 reports processed and categorised as either *'Smoke'* or *'Fumes'* with only 5 of these events being subject to an ATSB investigation. [183] The low number of events actually investigated by the ATSB places a considerable emphasis on the operator or pilot to provide the necessary data to enable safety trends to be revealed, something which is clearly not occurring.

A subsequent request to the ATSB by Professor Chris Winder of UNSW in 2009 for all *'Smoke'* or *'Fume'* events from 1990 to 2009 reveals in fact there were over 230 events for the period 1 April 2007 to 31 March 2009 and not 132 as declared to the media. The Australian International Pilots association advised: *'AIPA believes there is underreporting of aircraft environment contamination events... The ATSB may not have the information necessary to form a complete picture of the extent of any problems.'* [184]

UK Air Accidents Investigation Branch (AAIB)

The AAIB is part of the Department for Transport and is responsible for the investigation of civil aircraft accidents and serious incidents within the UK and is another source of data.

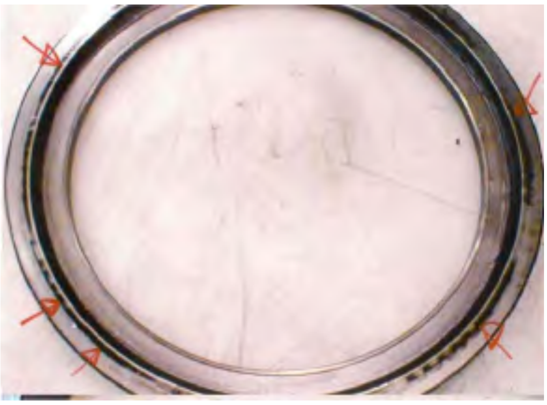
A search of their database from January 2006 to November 2007 reveals 37 contaminated air events, which the AAIB lists as being aware of occurring to UK registered aircraft which may include various levels of AAIB investigation. Investigations may range from a full-scale investigation to simply having basic data about the event. Of the 37 events relating to UK registered aircraft only 10 were publicly available for further investigation. The database also reveals 8 events occurring to German registered aircraft. Additionally the database contained 5 events, which were listed as *'incapacitation events'* occurring due to contaminated air on British registered aircraft and, 4 on German registered aircraft.

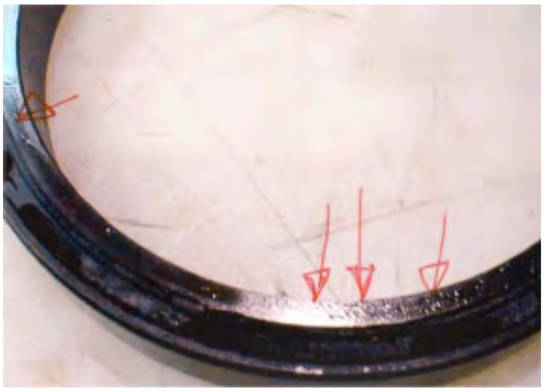
The AAIB reported that in the *'three-year period to August 2006 there had been 53 cases of fumes, abnormal odour or smoke or haze in the flight deck and/or cabin of UK registered public transport aircraft of various types… Around 119 of the cases had probably resulted from conditioned air contamination... commonly caused by oil release from an engine, APU or air conditioning unit or ingest on of de-icing or compressor wash fluid by an engine or APU, with consequent smoke and/or oil mist in the conditioned air supply to the fuselage. It appeared that in many of the cases, the crew members had found it difficult or impossible to establish the source of the contamination. Adverse physiological effects on one or both pilots, in some cases severe, were reported in 40 of the cases. A diversion was made in 31 cases.'* [169]

Swiss Büro für Flugunfalluntersuchungen BFU

The Swiss Aircraft Accident Investigation Bureau has recently published 4 known key reports concerning aircraft contaminated air. A 1999 report refers to a *'serious incident'* in which oil was identified as having leaked from bearing no. 2. A three engine ferry flight to the maintenance base was undertaken. [185] Oil residues in the air conditioning system were reported to be responsible for the toilet smoke alarm during the flight. Oil carbon deposits and surface wear were subsequently identified at the sealing surfaces of the no. 2 bearing, therefore no longer allowing complete sealing (refer Figure 6-6) that led to the oil leaks. The internal oil leak then mixed with the high pressure bleed air and passed into the cabin air via the high pressure compressor bleed port through to the air conditioning pack and then into the cabin air supply.

Figure 6-5: BFU report: 1800, BAe 146 RJ. 17 August, 1999: Oil seals





A 2003 report refers to a *'serious incident'* on an Avro 146 RJ in which a flight was aborted after smoke filled the passenger cabin. [186] The cause was reported as an O-ring (part of oil seal) that was incorrectly lubricated with petroleum jelly that combusted and generated smoke then released into the cabin air supply when the engine was operated at high power. Another *'serious incident'* occurred on an Avro 146 RJ in 2006, which was *'probably attributed'* to smoke from the APU entering the cabin via the air conditioning system on short final. [187] The smoke had a blue colouration with no discernable smell. Oxygen masks were not utilized by the pilots and an emergency evacuation was carried out. No oil related defects or other defects were found upon inspection with the aircraft released for service. The APU involved subsequently caused two further events with smoke and smell (one described as *'toxic smell')* after this serious incident. Further investigations following a flight 5 days after the first incident found oil related defects in the APU. A number of maintenance actions were applied to the APU, which was subsequently installed on another aircraft upon which white smoke filled the cabin. Another incident occurred a month later as the aircraft departed the terminal, after which the APU was sent to the manufacturer. The APU was determined to most likely be the cause at the time the report was written due to the chronology of the events.

A further *'Serious Incident'* occurred on a Swiss International Avro 146 RJ in 2005 that was attributed to the cockpit filling with fumes on approach which *'caused a toxic effect leading to a limited capability of acting of the co-pilot.'* [140] *'The fumes were caused by an oil leak as a result of a bearing damage in* *engine No. 1. The indicators for impending bearing damage were not correctly interpreted before the incident.'* The smell and fumes in the cockpit occurred even before the serious incident and the aircraft was released for further service several times before the event took place despite that the defect had not been rectified. The captain did not use his oxygen mask. The medical examination of the co-pilot showed a toxic effect had taken place.

German Bundesstelle für Flugunfalluntersuchung (BFU)

German Federal Bureau of Aircraft Accidents Investigation known as the Bundesstelle für Flugunfalluntersuchung (BFU) is the German federal agency responsible for air accident investigation. The purpose of BFU is to find out the causes of air accidents and how they can be prevented.

The BFU have investigated a number of contaminated air events however the exact number has not been confirmed by the author. A search of the BFU online database in their English website in November 2009, using *'oil'* as a search term revealed only six incidents, none of which were related to large commercial jet aircraft. Incidents previously known to the author such as instances with the following allocated case numbers 5X001-0/07, 5X003-0/07 or 5X009-0/06 were not available from an online search, which suggests the online search function is not suitable for online research.

Figure 6-6: BFU report: 5X008-0/06, Embraer 145. 28 June 2006

One other smoke/contaminated air event listed involved an Embraer 145 (BFU 5X008-0/06) as shown in Figure 6-6 departing the runway after landing with visibility due to smoke reduced to 20cm and subsequent engine inspection. The

UK AAIB database also listed more incidents to German registered aircraft than the BFU site itself did.

Irish Aircraft Accident Investigation Unit

A German registered Airbus A319 departed Dublin when several of the crew reported feeling unwell (with one cabin crew member unresponsive and the captain reporting tingling in arm) soon after take off with many of the passengers appearing drowsy or asleep. [33] Investigations were undertaken for contaminated amongst other causes. However, as no smell or smoke was evident (despite 2 of 15 personnel reporting feeling unwell during air quality tests and pilot reporting adverse effects on the ferry flight to Toulouse) and no fume related defect was found by the airline or manufacturer, no cause was identified and cabin air contamination was discounted as a possible cause. The AAIU reported 3 further cabin air quality events related to fumes with unusual smells and crew reporting ill effects in the following months based on different aircraft types with different manufacturers and airlines. In each case, no source could be identified.

A previous AAIU report for an Irish BAe 146 based on a 1997 incident noted a strong smell of fumes after take off, which became worse as the flight progressed. [188] *'On an earlier sector the same fumes were noted but they quickly dissipated.'* All the crew then experienced stinging of the eyes and nose, dryness of the throat, headache and breathing discomfiture and some dizziness amongst the cabin crew. An emergency was declared. The source of the fumes could not be isolated by alternate Pack operation. There were no complaints from the passengers regarding the air quality. Fumes and smoke in the cabin were caused by oil from the No. 3 engine No. 1 bearing seal entering the bleed air system.

US National Transportation Safety Board (NTSB)

The US National Transportation Safety Board (NTSB) is reported as being an independent US Government investigative agency responsible for civil transportation accident investigation. In this role, the NTSB investigates and reports on aviation accidents and incidents, certain types of highway crashes, ship and marine accidents, pipeline incidents and railroad accidents.

A search of the online database in November 2009 using the search term *'contaminated air'* with events that occurred to Part 121 flight operations from 1 January 2000, provided just one event allocated with the NTSB reference number SEA00IA062 and had occurred on 1 April 2000 to an MD-82 aircraft registered N934AS. Searching with the search terms *'oil fumes'* and *'oil mist'* generated no records and a search with the terms *'smoke AND oil'* generated just one event dated 10 April 2003 that occurred onboard an Airbus A300F4-605R aircraft registered N676FE. The report states that the aircraft operator FedEx, attributed the smoke to *'oil and another fluid, possibly glycol, contaminating the air-conditioning packs.'* A previous request to the NTSB for smoke/ fume related contaminated air events revealed just 5 events for the 10 years up to 2000. [112]

Like the online BFU database, the NTSB database, although more sophisticated, fails to enable a quantitative online search of contaminated air events and would appear the NTSB has reviewed very few contaminated air events over the years.

Various other data sources

There are many other sources of information that provide information about contaminated air events, most of which are rarely, if ever, reviewed. These come from a wide variety of sources. [2] A limited number of examples include:

- Australian Parliament Hansard: 90 fume events were reported by one airline from 2002 to 2006 on the BAe 146; [189]
- Industrial Relations Tribunal: BAe 146 operator in 2002 removed 141 engines stating, *'with the majority being related to air quality issue.'* while the operator average for this sized fleet was 36; [190]
- Pilot: Over 3 years to 2002 listed in excess of 67 contaminated air events in log book, crew reports, private diary; [84]
- Passenger reports: Robin Montmayeur: Passenger on United Airlines flight 201, December 13, 2000 (A320) – confirmed oil leak; *'The flight changed my life permanently';* [191]

- Union reports: In excess of 50 airline incident reports of contaminated air events between 1992 and 2002. 462 reports over 4 years of cabin crews reporting symptoms connected to air quality events on Boeing and Airbus aircraft; [73,192]
- Union: *'BALPA noted the case of a pilot with a charter plane who had experienced 150 fume incidents but had not reported any of these to the CAA';* [193]
- Internal airline report: Safety Occurrence Reports – 25 reports from 1 flight attendant such as; 26/3/01- VH NJZ, BAe 146 *'…once again we experienced an overwhelming surge of cabin fumes on descent… I would like to know what serious action is/will be taken to improve the cabin air quality of this aircraft… The reporting method is unreliable. Often FA (flight attendants) are reluctant to report 'cabin odour occurrences' and commonly feel that NJS does not take the matter seriously/or do anything about it. Therefore I believe the engineering department is not gaining a true indication of the frequency of odour occurrences';* [194]
- Alert Bulletin: NASA ASR report system: [195] NASA alerts Embraer regarding a voluntary ASRS report it had received with the reporter advising smoke and fumes were *'apparently caused by engine oil from some sort of faulty labyrinth seal… There were 5 such incidents in the past week… This illustrates to me the need for better quality CTL methods at the engine assembly line (Allison Rolls Royce). The engines had roughly 500 hours on them which is basically brand new… Smoke in the cabin can be catastrophic and I do not believe it should be overlooked as just bad luck';*
- Various insurance claims, legal cases (pilot loss of medicals, workers compensation cases, civil cases, superannuation payments) and medical reports; official inquiry evidence.

6.7 Discussion

Under reporting of contaminated air events has been acknowledged widely within the industry and is real, widespread and a global issue of concern, yet some industry funded regulators like the UK CAA refuse to accept this as fact. An in depth review of the data confirms that contaminated air events are not rare and adverse effects from such exposure are also not rare.

The regulatory databases used are unreliable, given the under reporting problem and data provided from such databases varies widely from one request to another. Given that crews are failing in most cases to report contaminated air events and that airlines are failing to pass on to the regulators a significant number of those events that are reported, which are themselves turning a blind eye to the problem; no reliable figure can be given to describe the frequency of contaminated air events. Additionally, it would appear few events are being passed onto the manufacturers as required. The aviation industry significantly under-reports the level of contaminated air events and in most cases denies that the reporting system is not working. The industry then uses this position as justification that there is not a critical problem.

The only data that can be used with any certainty are as follows:

- Significant under reporting is occurring. (APH 2000, FAA 2006, ACARM 2007) [2,61,66,67]
- Fume events are not rare. (USAF 1983, ATSB 2002, RAAF 2004) [63,64,65]
- Less than 4% of fume events are reported. (Michaelis 2003) [1]
- It is not possible to determine a reliable rate of contaminated air occurrences. (EASA 2009 [4]

Statistics frequently quoted to put a number on the frequency of fume events such as the following, while acknowledging there is indeed a problem; cannot be relied upon to suggest they represent the frequency of contaminated air events:

- Fume events are reported in 1% of flights. (UK COT 2007) [39]

- 0.86 events per day reported per day in the US. [158]
- 1 fume event per 66 flights (15/1000 flights: 1.5%). (Ansett, APH 2000) [21,61]

As an example, the UK Government position that fume events are reported in 1% of flights (based upon airline supplied data) does not support their later statements that fume events occurred in 0.008% (97/1.2 million flights) and 0.009% (116/1.3 million flights) of flights [135,136] based on its MOR database in 2008 and 2007 respectively. This is 125 and 111 times less respectively than previously acknowledged, based on airline records that may not even be reliable. This is just one of many examples demonstrating the regulator using unreliable figures so as to minimise the problem.

There are many reasons for under reporting and these all need to be tackled by the industry as a matter of urgency. Crews should be encouraged to report all contaminated air events without fear of recrimination or intimidation. Additionally, contaminated air detection systems should be installed to provide an automated process that would address many of the reasons why under reporting is occurring. The UK Government response to the House of Lords recommendation that an awareness fume event reporting campaign specifically be carried out aimed at pilots and airlines, was less than forthright as the specific requirement for toxic, noxious fumes was omitted from the response and no such campaign was undertaken. [157] As such, if the regulator is in reality resistant to contaminated air reporting, it is hardly likely that the situation will be positively addressed.

The difference between statistics due to under-reporting, varying data on internal databases and the ongoing failure of the industry to properly record such events, allow all parties to use flawed data to perpetuate well-entrenched positions with important health and safety trends ignored.

Industry statements that fume events are relatively rare or similar or *'with proper maintenance, operation, and design are anticipated to occur infrequently.'* [3,4,5,93] are inappropriate. Airbus advises oil contaminants do not enter the cabin under normal operating conditions and such leakages are 'extremely rare' and are 'conjectured to be present only after a very unlikely incident, and highly infrequently.' [92] Such statements are not supported by the evidence. While in the same document suggesting oil fumes are relatively rare, EASA correctly states *'it is not possible to determine a reliable rate of occurrence.'* [4] The reliance by aviation regulators and the industry to use figures that are flawed as a basis of frequency of events, [4] given the independent evidence available, should no longer occur.

In general, the regulations surrounding contaminated air defects on aircraft are not being followed. While a very low number of contaminated air events get reported and investigated, this process is often inadequate. [50,51,76] Most others slip between the cracks and a lot of objective information is deemed anecdotal by the industry. This allows an inaccurate picture of the real situation to develop, which is then accepted as reality, adopted as practice and defended with rigor at the expense of moving the issue forward towards a proper resolution. Therefore neglecting the health and safety of aircrew and passengers in the process.

There is a clear contradiction of how fume events are viewed within the aviation industry. Leaking synthetic jet engine oil at transient engine operations settings and the issue of engine oil seal bearing providing a complete seal over the whole engine operating range, provides the basis for oil leakage at lower levels frequently, being part of the process in which engines operate. However, varying interpretations are provided from within the aviation industry of what constitutes an oil seal leakage or a contaminated air event. Some suggest that *'the evidence indicates such exposures occur only when there is a mechanical malfunction.'* [18]

The failure to recognise that contaminated air events are happening far more frequently than acknowledged is allowing vital important health and safety issues to remain unaddressed. Key examples of the hazards of ignoring the true rate of events include: the high rate of crew impairment in such a safety critical job; the general failure of crews to use oxygen during fume events; the continuation of flight after fume events are reported or occurring and the fact that the regulators are effectively turning a blind eye and bar a few selected limited actions, the problem is deemed *'acceptable'* provided the frequency remains low. By turning a blind eye to the above and many other related factors, an unsafe situation is allowed to continue unaddressed. The issue is the frequency of this serious health and flight safety problem is anything but low and business interests are being placed ahead of crews and passenger health and safety. [196]

Despite the regulations unequivocally requiring all contaminated air events to be reported, the regulators are paying lip service to the adherence requirements under the legislation. The UK Government response to the House of Lords recommendation to undertake an awareness reporting campaign and the Government acceptance of the DHL view that many oil fumes are seen as normal and therefore need not be reported provide clear evidence of the regulator and Government disregard for the legislation and safety implications. [76,77,157] Likewise, British Airways clear advice that many reports do not require to be reported as a defect or mandatory report sent to the regulator and the FAA assessment of the number of fume events, despite only recently recognizing the reporting system was not working, again provides evidence of the system not working at airline and regulator level. [66,67101,147]

Aviation regulators are not taking appropriate action. Until the under reporting issue is addressed by the aviation industry or by an independent governmental agency, the scale of the problem cannot be identified. [7] Neither will it be possible to know the full health impact exposure to contaminated air is having globally on crews and the traveling public. The failure within the airline industry to properly ensure all events are reported and collated into one global database prevents the industry being able to undertake a proper risk assessment as to the impact of contaminated air on flight safety. These allow what is a clear flight safety issue to continue unchecked and at a frequency which is in fact unknown.

It is inappropriate to base research (safety, toxicity, health, etc.) of the contaminated air issue or selected actions to control the problem based on the frequency of contaminated air events. The number of events occurring is not known, however based on the design and operational characteristics of the oil seals, such events are not rare. There is enough evidence to support this and actions must take place to tackle the various problems as they are occurring, are significant and are a major flight safety and health risk for crew and passengers.

Whilst civil aviation has denied, and continues to deny, the scale and effect of these issues from both an under-reporting and medical effect perspective for over 30 years, the military now accepts that *‘the occurrence of smoke and/or toxic fumes in the aircraft cockpit or cabin is more common than is generally realised’* and *‘there is some evidence that continued exposure to small amounts of certain contaminants may produce chronic, long term, and irreversible damage to humans’*. [65]

6.8 Conclusion

Under reporting of contaminated air events has now been acknowledged widely within the industry and is real, widespread and a global issue of concern, yet most regulators continue to fail to accept this as fact. Under reporting was first acknowledged as occuring in 1977 and continues unabated over 33 years later.

There is no single international database to collate contaminated air events and the various databases used are totally unreliable. The problem of under-reporting involves crews and airlines, where fumes are seen as a nuisance and ongoing problem. The regulators are not requiring adherence to the regulations that require all suspected contaminated air events to be reported and are not ensuring adequate records are kept and the manufacturers, while aware of the problem, have done virtually nothing to address the problem.

This is a significant aviation safety matter to pilots, cabin crew and passengers where leak incidents affect the ability of pilots to fly planes safely or the ability of cabin crew to perform their duties as expected in either normal or in emergency conditions. Also, this is a significant health and safety matter to airline staff and passengers where leak incidents affect or may their health.

The issue of bleed air contamination is one involving design and expected functionality of how such systems work along with ongoing maintenance and operational/seal wear issues. The focus has been on the less frequent major maintenance failures, whilst ignoring the expected way in which such systems work.

EASA has correctly stated that it is not possible to determine a reliable rate of contaminated air occurrences but the vast majority of fumes are related to oil, while the FAA has recognized that under-reporting is occuring.

Aircraft contaminated air events are not rare based on the available evidence. Failure to accept this or continued use of inaccurate data allows aircraft to continue to fly in an un-airworthy condition with the flight safety and health implications for all those on board the aircraft remaining unaddressed. With the evidence available, this ongoing problem is foreseeable and one that has major implications for air transport, safety and human health.

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7 What they knew and what they did

7.1 Introduction

Over the years, the highly regulated aviation industry has developed a very sophisticated documentation process that is used in order to record activities and ultimately ensure aircraft are operated in a safe or airworthy manner. Some of this information relates to problems the industry has with oil leaks and contaminated air events and the consequences of such exposures. Much of these data are inaccessible and commercially confidential. However, there are enough data available to review some of what the industry knew about contaminated air and what it did about this problem over the last six decades. The selected information will be catalogued for the first time in one place and as such, should be considered significant and new.

This Chapter will review general airline industry data and action that has taken place over the years specifically related to contaminated air. Following this brief review, the specific case of the BAe 146 and BAe 146RJ aircraft for which there are considerable data available spanning over 25 years will be reviewed. Some of these data have previously been published. [1] A case study could equally be carried out on any particular aircraft model. This should be used only as an example of the type of information that is available to show the extent of the problem of contaminated air and related issues. General data on various aspects such as incidents, industry investigations and monitoring are covered elsewhere in the thesis.

The question as to clean air relating to the safety of air transport aircraft should be viewed in terms of the requirements of the airworthiness standards that must be complied with to enable the aircraft to hold a Certificate of Airworthiness, thereby allowing for the issuance of a Maintenance Release and subsequent operation. [2] There is a very extensive regulatory framework established within the aviation industry in order that an aircraft is designed to, and maintained in, an airworthy state.

While many suggest the issue of oil and hydraulic fluid contamination is not a major issue and a rare event, a review of industry data in some cases suggests otherwise. In fact, there is an extensive history going back over decades showing the history of cabin air contamination in some aircraft. However, most of this information is publicly unavailable. Therefore the data that is available should be reviewed in order to understand the contaminated air issue, given all modern commercial aircraft today (apart from the new Boeing 787) use bleed air.

The information about an aircraft's operation, defects and its continuing airworthiness is received from various sources, as information flows in both directions between the aircraft manufacturer and the operator, based on in service experience. The information, takes various formats including those listed below:

- Aircraft technical log defect reporting and action taken by engineering division;
- Defect reporting from aircraft operator to the regulatory authority;
- Defects reports to regulators from Type Certificate holders;
- Service Bulletins (SB) - These are bulletins issued by the manufacturer based upon information gained from the field identifying inspections or modifications on a variety of compliance options such as for information only, optional or recommended, generally with a statement as to when the recommended action might be undertaken. It will list the title of the modification, effectivity, reason and in some cases background for its release, description, compliance, man-hours, costs etc. In rare cases these may be issued as an alert service bulletin indicating a higher status. The manufacturer cannot make the modifications or inspections mandatory (see Airworthiness Directives/ADs below);
- Service Information Leaflets or Letters (SIL) or equivalent – Issued by manufacturers so as to disseminate information generally supporting a service bulletin - related modification or inspection;
- All Operator Letters or Messages or equivalent (AOL/AOM) – Information sent by manufacturer to aircraft operator on a particular subject with a selection of people to whom it is intended to be seen e.g. engineering, maintenance staff, flight operations, flight and or cabin crew;

- Manufacturers operations manual/notices to aircrew and operators – Information provided to operators and aircrew by manufacturers highlighting operational information;
- Engineering Releases (ER) or equivalent – Internal airline records on modifications undertaken;
- Engine maintenance manuals or equivalent – Lists modification details and procedures;
- Informal communications within or between aircraft operators, manufacturers, crew, unions and other interested parties;
- Airworthiness Directives (AD) – *'An airworthiness directive is issued by the regulators when they feel sufficiently concerned that a real or potential risk exists to the safe operation of the aircraft.' [*3,4] ADs involve a mandatory requirement to undertake a manufacturer Service Bulletin or alert SB and are issued by National Aviation Regulators when they feel a safety risk exists or could exist;
- Other industry data.

In order for the information to be set out in a uniform industry wide standard, the Air Transport Association (ATA) has devised various chapter codes. These codes relate to particular subject matters and identifies to all what the particular topic is. Selected codes include those shown in Table 7-1.

Table 7-1: ATA Codes, Chapters and Subsections

Code	Chapter Heading	Chapter Subsection
21-00	Air Conditioning	General
21-10		Compression
21-20		Distribution
21-30		Pressurisation control
21-40		Heating
21-50		Cooling
21-60		Temperature Control
29-00	Hydraulic Power	General
30-00	Ice and Rain protection	General
35-10	Oxygen	Crew
35-20		Passenger
36-00	Pneumatic	General
36-10		Crew
36-20		Passenger
45-50	Information Systems	Miscellaneous
49-00	Airborne Auxiliary Power	General
49-10		Power plant
49-20		Engine
49-30		Engine Fuel and Control
49-40		Ignition/Starting
49-50		Air
49-70		Indicating
49-80		Exhaust
49-90		Oil
71-0	Power Plant	General
71-6		Air Intakes
72-0	Engine- Turbine	Engine- Turbine
75-00	Air	General
75-10		Engine Anti-Icing
75-20		Cooling
75-30		Compressor Control
75-40		Indicating
79-0	Oil	General
79-20		Distribution

7.2 What the airline industry knew – excluding the BAe 146

There is a variety of information known by the aviation industry suggesting that there are hazards associated with the use of synthetic jet engine oils. A review of a limited number of documents highlighting the awareness will be broken down into categories, many of which will have been covered elsewhere in the thesis.

7.2.1 Regulatory

Regulators around the world have been aware of the contaminated air issue for over 50 years. In 1953, the US aviation regulations in relation to air quality were expanded to include a requirement to provide *'a sufficient amount of fresh air to enable the crew members to perform their duties without undue discomfort or fatigue'*, noting that *'ventilating air in crew and passenger compartments shall be free of harmful or hazardous concentrations of gases or vapors.'* [5] These were modified again in 1964 under the FAR airworthiness standards FAR 25.831, however the content was very similar. [6] This indicates there was awareness that aircraft air could become contaminated. The USSR airworthiness regulations in 1985 listed that certain substances must be below certain limits including vapours and aerosols of synthetic engine oils, CO, aldehydes and aromatic hydrocarbons [7] and in 2004 the Russian airworthiness regulations specifically advised that in addition to CO and CO_2, when considering harmful and hazardous concentrations of gasses or vapours, the *'Content of other toxic impurities must not exceed'* given values including: TCP: 0.5 mg/m^3; Synthetic oil vapors and aerosols – 2 mg/m^3; Dioctyl sebacate – 5 mg/m^3; along with acrolein, formaldehyde among others. [8]

In 1976, the UK Civil Aviation Authority issued the document: British Civil Airworthiness Requirements. Chapter D6-11 covers ventilation and pressurisation of crew and passenger compartments. [9] This covered ventilation (section 3.2.2), noxious vapours (section 3.3.10(d)), contamination (section 3.3.10(e)), and failure of components (section 6.3). EU Legislation (JARs) similar to the US FARs (25.831) was then established around 1979 and have since been replaced by the EASA CS airworthiness regulations such as 25.831.

In practice, the industry assumed part b) of the aviation airworthiness ventilation regulation (FAR/CS 25.831b) meant that only CO, CO_2 and ozone had specific limits that must be met. [10,11,12] For example, BAe demonstrates that its 1990 certification test report for the air conditioning system measured CO and CO_2 only. [13] However, the regulation clearly stated that the air must be *'free of harmful or hazardous concentrations of gases or vapors.'* There was, however recognition that a large amount of fresh air airflow may be required in part for *'control of smoke or toxic fumes.'* [14]

The intent of FAR 25.831 is *'to supply passengers and crewmembers with enough uncontaminated air to provide reasonable comfort during normal operating conditions and also after any probable failure of any system that would adversely affect the cockpit or cabin ventilation air.'* [15] However, the EASA equivalent regulation (CS 25.831a) requires that each crew compartment is required to have enough fresh air to enable crewmembers to perform their duties without undue discomfort or fatigue, while passengers were not referenced in a similar manner to the FAR before the 1996 amendment.

The European certification specifications, airworthiness and acceptable means of compliance to determine suitability of compressor engine bleed air for direct use in the aircraft cabin pressurization or ventilation system requires contamination *'tests to determine the purity of the air supply.'* [16] The certification safety analysis must show that hazardous engine effects or major engine effects are predicted to occur at a rate not in excess of that defined as *'extremely remote'* (probability of less than 10^{-7} per engine flight hour) or *'remote'* ($<10^{-5}$) respectively. [17] The safety analysis must include compressor bleed systems. Hazardous engine effects include *'concentration of toxic products in the engine bleed air sufficient to incapacitate crew or passengers'*, *'…no effective means to prevent flow of toxic products to crew or passenger compartments'* or *'degradation of oil leaking into the compressor air flow.'* Major engine effects include *'concentration of toxic products in the engine bleed air sufficient to degrade crew performance.'* [17]

The APU certification tests must likewise consider hazardous and major APU effects to the same degree of probability. [18] Hazardous APU effects include *'concentration of toxic products in the APU bleed air for the cabin sufficient to incapacitate crew or passengers',* including *'degradation of oil leaking into the compressor air flow'.* Major APU effects include *'concentration of toxic products in the APU bleed air for the cabin'* sufficient to *'degrade crew performance.'* Again the APU safety analysis must include the compressor bleed systems. [18] For APUs that provide compressor bleed air, the air intake duct must not release hazardous amounts of toxic gases into the bleed air. [19]

The SAE aviation committee, realizing the bleed air quality (limited) specifications had their origin in military specifications, has set various non mandatory contaminant levels considered applicable to the aviation setting in *'normal operations.'* [10,11,20,21,22,23] In addition to CO and CO_2, limits for formaldehyde, acrolein and acetaldehyde, among others have (varied over the years/no level for oil or TCP) been published. However *'The contamination levels provided by these standards (SAE 4418) are intended for qualification of bleed air equipment and should not be interpreted as providing contamination limits for breathing air.'* [10] A 1987 SAE document demonstrates this committee was concerned about bleed air contamination: [24]

- *'4.11 – Bleed air quality: requirements should be imposed on the engine manufacturer regarding the quality of the bleed air supplied to occupied compartments: recommendations are as follows: Under normal operating conditions, the engine bleed air shall be free of engine generated objectionable odors, irritants and/or toxic or incapacitating foreign materials… following any type of engine or engine component failure, the engine bleed air shall not contain the above substances to a harmful degree.'*

The US FAA airworthiness standards also require that aircraft systems and equipment *'must be designed to ensure that they perform their intended functions under any foreseeable operating conditions.'* [25] The regulation also requires that *'any failure condition which would prevent the continued safe flight and landing of the airplane is extremely improbable, and… any other failure* *conditions which would reduce the capability of the airplane or the ability of the crew to cope with adverse operating conditions is improbable.'*

In 2001 BAe advised that *'In the past, oil leaks and cabin/flight deck odours and fumes may have come to be regarded as a nuisance rather than a potential flight safety issue.'* [26]

In 2002, the US FAA stated that *'No present airplane design fulfils the intent of 25.831 because no airplane design incorporates an air contaminant monitoring system to ensure that the air provided to the occupants is free of hazardous contaminants.'* [27]

All instances of *'smoke or toxic or noxious fumes'* in addition to being defects are reportable to the regulator. [28,29,30,31,32,33] However, in 2006 the US FAA acknowledged that '*there are numerous air carriers/operators who may not have reported these events as required by regulation'.* [34] Under reporting was increasingly recognized as occurring by the RAAF and Australian Senate Inquiry [35,36] and seen as not rare by the ATSB [37] and USAF when stating:

- *'Smoke and fumes in the cockpit is not a rare event and a clear threat to flight safety due to acute toxic effects.'* [38]

EASA recognizes *'it is not possible to determine a reliable rate of occurrence*', [39] while the Transportation Safety Board of Canada stated in an interim report investigating the fatal accident of the Swissair MD11 that *'within the aviation industry there has been belief that odours are often a 'non event' diminishing concern about minor odours.'* [40]

Despite the requirement for clean air in aircraft being an airworthiness issue and where a safety risk is identified an AD is supposed to be issued, in fact very few have been issued in relation to contaminated air. In 2000 the US FAA issued an AD for various MD 80 series aircraft for modifications to prevent *'smoke and odour in the passenger cabin and cockpit due to hydraulic fluid leaking into the APU inlet, and subsequently, into the air conditioning system.'* [41] Several ADs have been issued with regard to leaking oil on the BAe 146, indicating an unsafe condition exists, however no other ADs have been issued for any other aircraft types leaking oil into the air supply.

7.2.2 Awareness of health and hazardous effects

In 1952, the National Advisory Committee for Aeronautics published a report noting that synthetic oils were required to satisfy the requirements of future lubricants of gas turbine engines. [42] Lubricant requirements were noted to be complicated by high *'soak back'* temperatures of the bearings (approaching 500°F (260°C)) which, cause thermal degradation of the lubricant. Higher operating temperatures with newer engines require the use of synthetic oils with *'speculation about probable toxicity and corrosiveness at elevated temperatures; these properties have not yet been adequately studied... The phosphonate esters as well as certain phosphate esters may be useful in future lubricant problems.'* [42]

In 1953, the Aero Medical Association (AsMA) clearly stated that pyrolised oil *'can contain irritant and toxic aldehydes and other dangerously toxic products of incomplete combustion… Even a small degree of bodily impairment from toxic gases would lead to increased pilot error and so be hazardous in aviation.'* [43]

In 1954 both the military and the aviation industry were aware of the need for toxicological information involving the thermal decomposition of lubricants and hydraulic fluids. Fogs formed at 400-550°F (204-288°C) were *'much less toxic than those formed at 600°F'* (260°C) with toxicity related to time to death. The toxicity of the products arising from the thermal decomposition of the synthetic lubricant was derived largely from the principal ingredient, the base stock and only slightly from the mixed TCP isomers while the products of thermal decomposition were found to be *'much more toxic'* than the undecomposed (TCP) material. *'In the case of the esters… aldehydes, carbonyls, carbon monoxide and undecomposed particulate matter were found in the atmosphere of the chamber. In the case of the tricresyl phosphate, free cresols, undecomposed tricresyl phosphate and carbon monoxide were found.'* The fogs produced pneumonitis and degenerative changes of the brain, liver and kidneys. [44,45]

The awareness of the bearing and lubricant problems in turbine engines operating at high speeds and temperatures was a major issue for the military in the 1950s with non toxicity over the whole temperature range listed as one of the six lubricant general requirements. [46] A further 1956 industry supplier report states that zero oil leakage, which is chiefly necessary due to the *'common practice of using compressor bleed air to pressurize or refrigerate aircraft cabins'*, is difficult to obtain under all operating conditions, with any oil leakage into the compressor air flow able to *'cause serious cockpit contamination problems due to the formation of toxic fumes.'* [47]

According to a 1956 Esso memo, [48] an unpublished and unsighted British Ministry of Supply (predecessor to MOD) study heated 2 synthetic engine oils to 572°F (300°C) and exposed animals for up to 6 hours and human volunteers for 2 hours to the fog/oil vapours in a study chamber. [49] The fogs produced varying degrees of mucous membrane irritation and some respiratory difficulties in the animals with all animals returning to normal after 24 hours and were healthy after 14 days. The majority of human volunteers (exposed to *'similarly generated oil vapors'* in 10% disbursement of oil per litre of air compared to animals) complained of *'transient dryness of the throat and slight irritation of the nose, with occasional slight eye irritation, sniffing and slight headache. There were no complaints of nausea and all were able to carry out normal functions.'*

The 1956 Esso memo [48] referred to the 1954 Treon USAF [44,45] research and reported that the inhalation of synthetic oil mists constituted no more of a hazard than associated with conventional petroleum oils. The report stated that fogs generated at 600-700°F (316-371°C) were toxic to animals but were tolerated well when heated to 400°F (204°C). Based on the Treon studies and the British data (confirming the Treon studies) Esso concluded there was *'no serious toxic hazard associated with the use of synthetic diester-type lubricating oils... the problem of cabin fogs or smokes seems to resolve itself into the engineering control of a nuisance'* and *'should be eliminated by whatever means, engineering or otherwise.'* The risks were identified as dermatitis if excessive skin contact occurred and eye irritation. The report however advised that inhalation of mineral and synthetic oil mists *'should of course be avoided.'* Based on the USAF/Treon research, Esso advised it was uncertain if *'toxic effects were produced by the combined action of demonstrated decomposition products or by the action of some unidentified toxic product of decomposition.'*

In 1962 an internal industry document reports that: [50]

- *'The utilization of engine compressor bleed air for cabin pressurization and air conditioning exposes the crew to air which could possibly be contaminated with decomposition products of MIL-L-7808 lubricant… a small leak in the front compressor section of the engine may allow the lubricant to escape from the engine and pass into the compressor bleed air section where under high compression and temperature the oil breaks down chemically forming toxic compounds, thus contaminating the bleed air going into the cabin… The extent of the contamination would be governed by the small amount of lubricant sealed in the bearings. The engine is the main source of bleed air contamination and the extent of the contamination is governed by the oil leakage rate of the front compressor seals… it cannot be overemphasized that only oil lost in the compressor section of the engine contributes to bleed air contamination.'*

The failure of the pre-lubricated bearings of the air cycle machine was listed as the other source of contamination with the possibility of the formation of gases such as aldehyde and carbon monoxide. [50] However the concerns were minimised by suggesting the Treon laboratory studies were not conducted in an aircraft using bleed air with Lockheed-Georgia Company studies on the C-130 and Jetstar aircraft indicating *'bleed air contamination is not a problem.'* Bleed air contamination simulated tests on the C-141 aircraft were assumed to vary with the effects of dilution, induction time and temperature. Additionally, with the range of concentration of aldehydes and CO in the crew compartment and the very short length of time of exposure in a severe leak scenario (due to oil exhausted in very short time and engine isolated within 2 minutes) said to pose no danger as MAC values are based on 6 hours/day for long periods. However, the simulated bleed air tests did cause *'strong irritation to the eyes and to the lining of the nose and throat.'* [50]

Around the 1950s and 1960s it was recognized that early TCP/TXP (tricresyl/trixylyl) production was shown to be neurotoxic and as a consequence of this finding, the o-cresol content in the feedstock was strictly controlled at very low levels. [51,52] Suppliers of tricresyl phosphate have for many years restricted the ortho content to less than 1% in order to minimise the possibility of peripheral nervous system effects. [52,53] Great Lakes manufacture a range of phosphate esters, including TCP, which are used as antiwear additives in lubricants. They are included at below 2% in lubricant formulations (around 3% in aviation lubricants). Over 90% of the phosphate ester antiwear additives used in lubricant manufacture globally are iso propyl phenyl phosphates/IPPP (Europe/Asia) or tertiary butyl phenyl phosphates/TBPP (North America). Neither IPPP nor TBPP products contains TCP. [52] The products were said to be growing in use because of their excellent health, safety and environmental properties. Over 40 years ago (mid 1960s), TCP was replaced by the two phosphate esters IPPP or TBPP. Two markets had TCP containing lubricants specified and did not wish to change - military and aviation. TCP is still used by these markets today but the global volume is small. [52]

In 1965 the US Naval inhalation studies of triaryl phosphates found it *'highly suggestive that components other than ortho tolyl groups have significant toxicity or are capable of synergizing or potentiating other triaryl phosphates.'* [54]

A 1966 Esso statement on the toxicity of Esso 2380 warned that at temperatures in excess of 500-700°F (260-371°C), synthetic lubricants *'will probably undergo pyrolysis and release decomposition products of varying degrees of toxicity. Care should be taken to avoid exposures to mists or vapors of oils heated to extreme temperatures… 2380 Turbo oil… may cause skin irritation and dermatitis after prolonged excessive contact… Avoid excessive skin contact and inhalation of mists and vapors released on heating.'* [55] Esso recognized that no threshold limit (maximum allowable concentration) for the 8 hour working day had been established for synthetic lubricants, however exposures should be kept below the mineral oil threshold level of 5 mg/m^3 set by the ACGIH. Similar assessments were reported for earlier oils such as the synthetic di-ester oil Esso Turbo Oil 15 and 35. [56]

A 1966 Douglas Aircraft Corporation report stated that: [57]

- *'In many cases contamination problems were encountered. The major contaminants were traceable to lubricating oil leaking into the engine compressor through the bearing seals… although the oil itself was not especially objectionable, the high temperatures encountered within the engine compressor caused the oil vapour to decompose into extremely* *noxious and irritating substances. Several unexplained fatal crashes involving single pack carrier based turbine powered aircraft with direct bleed air conditioning systems installed were attributed (rightly or wrongly) to contaminated engine bleed air.'*

The report stated that aircraft in the design stage were using advanced technology engines with: [57]

- *'Much higher compression ratios resulting in bleed air extraction temperatures, even for the lower bleed stages, well above the critical decomposition temperature of conventional engine lubricating oils. These higher bleed temperatures will prevail during most normal operating conditions and not for short-terms, hot day, operation as is the case for current jet-powered aircraft.'*

The critical temperature referred to was the earlier 1954 Treon USAF research work determining 600-700°F (316-371°C) to be the critical temperatures. Douglas reported that the DC9 and B727 were designed to minimize bleed air contaminations during normal operating conditions as well as using interstage bleed ports with automatic switching systems to ensure the bleed air temperatures would almost always remain below the critical temperatures for the oils.

The US FAA approved commercial jet aircraft using bleed air for environmental control systems that could show that: [57,58,59]

1) *'during normal operating conditions proper bearing seal design will prevent lubricating oil from ever entering the compressor air stream;*
2) *In the unlikely event of a bearing seal failure the bleed air temperature will either be below the critical level (above which harmful contaminants begin to form) or the exposure will be so short that even extremely high oil leakage rates can be tolerated without ill effects to crew or passengers.'*

However, engines and aircraft in the conceptual design stage would be unlikely to pass either the military or civilian bleed air purity requirements given the hotter temperatures involved, as distinct from the 1960's *'rather vague'* US FAA regulations, that were likely to be revised to become more stringent. [57,60]

Given the growing concern over the *'contamination problem'*, shown by (Air Force, Navy, airframe and engine manufacturers), various efforts were undertaken in the mid 1960's to address the problem. [57] The US FAA undertook laboratory experiments to isolate the various contaminant substances resulting from thermally decomposed lubricating oils and to evaluate the effects on animals with attempts made to correlate the results of the tests with threshold safety values for humans. [57,60] The US FAA report to date remains unsighted. The engine manufacturers redesigned engine bearings, seals and bleed air extraction ports to prevent oil from entering the compressor section during normal operations and to minimize the amount of contamination extracted with bleed air in the case of a bearing seal failure. The airframe manufacturers installed special filters in the bleed air lines or incorporated the ability to isolate a contaminated air supply in the case of multi- engine aircraft. The Navy issued an operational order requiring that *'all crew members of turbine powered aircraft with direct bleed air systems installed use 100% oxygen from takeoff to landing.'* [57]

A 1967 study undertaken for Esso and Humble Oil, [61,62] exposed animals via inhalation to Esso Turbo oil 15 and 2380 that had been heated to 500°F (260°C) or 700°F (371°C). The animals exhibited paralysis in the hind quarters while autopsies revealed *'gross changes suggesting severe irritation of the respiratory tract consisting of edema, inflammation and gross hemorrhage into the bronchioles and alveoli.'* [61] The apparent cause of death was deemed a *'result of severe irritation to the respiratory tract.'* Greater toxicity was shown at the higher temperatures. McDonnell Douglas reported concern at the findings as they had expected lower levels of toxicity to be shown over previous oils studied. [62,63]

- *'The design of the environmental control systems for the DC-9 was greatly influenced by the availability of clean engine bleed air for cabin pressurization'* and ventilation, with simplicity being of utmost importance. [64]

Various studies of the oils and contaminants are known to have taken place over the years. A few examples include the Douglas Aircraft Corporation simulated oil leak investigations at Edwards Air Force Base commenced in

1963 into *'clean air'*, thought to *'help relieve stringent self-imposed restrictions on bleed air system design.'* [65,66,67] Samples were analyzed for CO, CO_2, total hydrocarbons and aldehydes in the bleed air, however bleed air temperatures in phase 1 of the testing were restricted to 600°F (316°C) and methodological problems were highlighted such that further tests with the same set up were deemed a *'waste of time'.* Further investigations investigated oil exposed to temperatures of 700°F (371°C) with changes in methodology as aircraft pneumatic systems could be simplified if it was shown that it was safe to take bleed air at high temperatures. [68] As such, the investigation questions raised were: what is the maximum oil leak rate; 2) how much oil enters the bleed air; what is the toxicity and nuisance level as a function of bleed temperature; 4) can the oil decomposition products be detected or removed? [68]

In 1969, Pratt and Whitney undertook a *'bleed air purity test'* for the JT3D-3B and TF33-P-7(C 141 aircraft) engines. [69] Individual compounds were not analysed as the total oil breakdown products were found to be less than individual limits for each substance. The letter reports that Lockheed had requested to use 16th stage ID bleed on the C-141 engine to *'supposedly reduce bleed air contamination since their design consisted of using 16th stage air directly for cabin pressurization.'* [69] The Pratt and Whitney letter was in response to a request from Douglas Aircraft Company investigating the quality of bleed air as they wished to *'extract breathing air from the 12th stage OD port as well as the 16th stage ID port.'* [70] Favorable bleed performance was said to be *'attributed primarily to good seals'* and it was considered that it did not matter where the air was extracted from in the gas path and therefore it would not be feasible to lengthen the engine TF33-P-7 to incorporate 12th stage ID bleed. [69]

A McDonnell Douglas report in 1970 advised that based on the 1969 oil leak rate investigations, engine companies were consulted regarding leakage rates and the petroleum industry was surveyed regarding standards on toxicity for oil decomposition. [68] The aircraft manufacturer reported that: [68]

- *'Contamination of engine bleed air by engine oil, once a serious problem, has been almost eliminated, by the efforts of engine manufacturers. Nevertheless, the possible consequences of a severe oil leak are* *sufficiently serious to make additional knowledge on the subject desirable. Current Douglas design practice is to guard against the possibility of toxic products of oil decomposition occurring in the air conditioning system by taking only low temperature bleed air.'*

In 1977, a military investigation of crew in flight incapacitation attributed to an *'inhalation exposure to aerosolized or vaporized synthetic lubricating oil*' stated that *'in cases of jet engine seal failures, these oils are subjected to high temperatures and pressures and contact with hot metal surfaces before they are presented for inhalation. These conditions may catalyze reactions that yield toxic products.'* [71] The report specifically theorizing TOCP could be at the centre of the problem, advised that *'the inhalation toxicology of these synthetic oils has received little attention, perhaps due to the obvious complications of dealing methodically with such a complex mixture of organic compounds.'*

USAF studies in 1979 found that the heated engine oils and hydraulic fluids produced *'significant quantities of highly toxic compounds.'* [72]

In 1981, the Society of Automotive Engineers (SAE) noted in an Aerospace Information Report *'Engine compressor bearings upstream of the bleed ports are the most likely sources of lube oil entry in the engine air system and thence into the bleed system contaminating the cabin/cockpit air conditioning system ...at temperatures above 320 deg C this oil breaks down into irritating and toxic compounds.'* [73] The 2005 version of this report deleted the reference to *'toxic'*. SAE reconfirmed the concerns of the decomposition products in 2005 when stating: [10]

- *'Thermal decomposition of lubricating oil, hydraulic fluid, and fuel take place within engines and APUs. If this occurs, the chemical species can differ from the original fluid compounds.'*

Commercially used triaryl phosphates are known to begin to breakdown (decomposition or evaporation) at temperatures above 300°C (TCP: 333°C; TBP: 283°C) said (incorrectly) to be *'well above operating temperatures.'* [74] Pyrolysis of phosphate esters have shown that the decomposition products are mainly unsaturated hydrocarbons and acidic phosphate esters, with triaryl esters being more stable than trialkyl esters. [74]

A McDonnell Douglas report from (circa) 1980 regarding a meeting between the US FAA, Pratt and Whitney and Douglas reviewing acceptance of bleed air following release of oil into the compressor indicates that *'the approach used in the past is that an indicator, in the form of haze, odor and irritant, exists to alert the crew to the contamination and that the air from the offending engine can be shut off before hazardous conditions de*velop.' [75] Earlier in 1965 and 1966 Douglas had used this approach to justify bleed temperatures of 580°F (304°C) which were subsequently raised to 670°F (354°C). Justification was based upon the earlier 1954 Treon WADC report [44,45] with the engine assumed to be out of oil in 1.7 minutes compared to the two hours the guinea pigs were exposed to oil mists without harm, thereby indicating that bleed air heated to 700°F (371°C) *'should not be unsafe to use in occupied areas.'* Therefore bleed air used for circulation for occupied compartments of the DC-9 taken from the JT8D-209 and 217 engines *'meets the intent of FAR 25.831 (c).'* [75] US FAA approval according to Douglas would include using emergency procedures titled *'Air Conditioning smoke/fumes'* involving crew (pilots) putting on oxygen masks and selecting air conditioning switches off one at a time.

A 1981 report by Royal Dutch Shell states that *'some commercially available lubricants are being stressed to the limits of the fluids capabilities.'* [76] The report advised that the emphasis on reducing specific fuel consumption is accomplished partly by raising engine operating temperatures resulting in higher heat loads on the lubricant, thereby necessitating oils with greater thermal and oxidative stability. A similar report by Mobil in 1985 recognized that *'since the early 1970's, the dominant trend in aircraft gas turbine engines has been increasing fuel efficiency. This has resulted in higher operating temperatures which, along with other engine design changes, place additional stress on the lubricant.'* [77] This concern has been more recently been highlighted as aerospace fluids and lubricants, given the weight concerns for all components, are required to withstand extremely severe levels of stress as small volumes are used and must operate at extremely high and low temperatures. [78] The ongoing need to increase fuel efficiencies in more severe operating environments and at higher operational temperatures will require improved ester based lubricants with increased upper temperature capabilities, however this *'will require a careful balance of ester base stocks and improved additives'.* [78] Additionally other classes of synthetic lubricants are under consideration for when the engine operational temperatures exceed the limits of ester-based lubricants.

In 1983 Mobil, a major manufacturer of jet oils stated: [79]

- *'If cabin air becomes contaminated with any lubricant and/or its decomposition products, in sufficient quantities, some degree of discomfort due to eye, nose and throat irritation could be experienced. Problems like these can be generally traced to improper design, improper maintenance or malfunctioning of the aircraft.'*

In 1983, the USAF advised that a number of toxic substances used in aircraft including oils had *'acute and long-term effects.'* [38] The NTSB accepted that *'There are certain instances in which chronic or repeated exposure may sensitise a person to certain chemicals so that later concentrations in the ppb may later illicit an acute hypersensitivity type reaction.'* [80]

The US FAA 1983 inhalation studies of the oils commented on the NTSB report noting the *'NTSB approach did not eliminate the possible presence of an additional component with significant animal toxicity.'* [81]

Further Naval studies of the oils and hydraulic fluids in 1989 found that *'it is possible to generate large quantities of TMPP from Exxon 2380 oil under laboratory conditions and therefore should not be used in the US Navy inventory; All polyol ester based synthetic oils in the U.S. Navy inventory should be tested for toxic byproduct production and research should be initiated for overall toxicity of combined, combustion byproducts rather than for any individual combustion product present.'* [82] These results involving Exxon 2380 were *'found to be in good agreement'* with the results obtained from the NTSB and University of Colorado. [82] The USAF and US Navy conducted a number of studies confirming the concern of the reaction of TMP base stocks with TCP in lubricants at temperatures as low as 250°C. [83,84,85,86]

A 1991, Allied Signal Aerospace report on aircraft reporting dirty socks odours states *'very little work has been done in the aviation industry to pinpoint the chemical compounds causing such odours …no single compound could be* *pinpointed which in and of itself could cause this odour ...the odour appears to be coming from breakdown products of the oil'* and that *'no contaminant appeared to be that great, but they do act in synergism and their combined effect could be enough to trigger the odour complaints.'* [87]

A 1994 and 1997 MIL specifications document, (applicable to all departments and agencies of Department of Defence) superseding earlier versions list the specifications of lubricating oils meeting MIL-PRF-23699 E and F. [88,89] These key documents state that:

- *'3.6 Toxicity. The lubricating oil shall have no adverse effect on the health of personnel when used for its intended purpose.'*

The 1997 MIL-PRF-7808L specification (synthetic jet engine oil) uses the same warning as shown above. [90]

However the recently created SAE specification (new civilian oils required to meet this with oils certified prior to 2006 grandfathered in to meet this) for aero an aero-derived gas turbine engine lubricants (AS 5780) does not mention health hazards or toxicity. [91] The specification requires only that the substances in the oils must comply with all *'legal, environmental, toxicological and regulatory requirements of the countries in which the products are manufactured and sold.'*

1995 USAF studies investigated the inhalation toxicity of vapour phase lubricants and found that the process of vaporization was causing a change in the compound TCP, resulting in the potential to produce neurotoxicity at lower levels than previously thought. [92] Therefore caution was recommended when using triaryl phosphate vapour phase lubricants. These were followed up with further USAF research in 2002. [93]

The 1995 MJO II MSDS in Australia states *'Harmful by Worksafe criteria',* whilst the 1999 US MSDS states:

- *'US OSHA HAZARD COMMUNICATION STANDARD: Product assessed in accordance with OSHA …and determined to be hazardous.'*
- The 1997 and 2004 Mobil Jet Oil II MSDSs state: '*This product is not expected to produce neurotoxic effects under normal conditions of use*

and with appropriate personal hygiene practices. This product contains tricresyl phosphate (TCP). Overexposure to TCP by swallowing, prolonged or repeated breathing of oil mist, or prolonged or repeated skin contact may produce nervous system disorders including gastrointestinal disturbances, numbness, muscular cramps, weakness and paralysis.' [94]

- *'This product is not expected to produce adverse health effects under normal conditions of use and with appropriate personal hygiene practices. Product may decompose at elevated temperatures or under fire conditions and give off irritating and/or harmful (carbon monoxide) gases/vapors/fumes. Symptoms from acute exposure to these decomposition products in confined spaces may include headache, nausea, eye, nose, and throat irritation.'* [95]

In 2000 Mobil advised *'Exposures to aerosols or vapours in aircraft cabins are not what we would refer to as "normal use".'* [96] Exxon studies advised neurotoxicity should not pose a hazard under realistic conditions of exposure. [97]

BP stated in 2009: [98]

- *'Health studies have shown that under normal conditions of use, turbo oil presents a low risk to human health. The major health risk from exposure to turbo oil is temporary irritation of the eyes, skin, and respiratory tract. Temporary irritation is a common hazard of most petroleum hydrocarbons and synthetic lubricants, like turbo oil. Irritation occurs when product is applied directly to the eyes, repeatedly to the skin, or when high levels of vapors or mist are inhaled. Because sensitivity to irritation can vary from person to person, direct contact with the eyes and skin, and inhalation of vapors or mist should be minimized. Prolonged and repeated skin contact with turbo oil can also cause temporary dermatitis.'*

Mobil was aware in 1990 that exposure standards for TOCP may not be protective for exposure to TCP. [99] However the increased toxicity of the other ortho isomers over TOCP (10 and 5 times more toxic) had been recognized in

1958 (Henschler) and were publicly recognized by Mobil in 1999. [100] Other Mobil studies found an unexpected level of neurotoxicity in jet oils containing 3% TCP and less than 0.02% TOCP (less than 0.5% TOCP in the TCP) and suggested little consideration had been given to the neurotoxic potential of the other isomers in the product. [101] One of the manufacturers of TCP for turbine engine synthetic lubricants reports that historical concerns had been raised about neurotoxicity and toxicity of the decomposition products of triaryl phosphates (including TCP) used as fire resistant fluids and lubricants since the 1950s. [51] While recognizing that toxicity data is not complete, the manufacturer, FMC Corporation reports that:

- *'Phosphate esters can produce "smoke" on contact with hot surface and concerns are sometimes expressed regarding the effects of inhaling their degradation products. However the white mist which is frequently produced is predominantly vaporised phosphate ester, that is, without significant degradation. With decomposition this darkens substantially. Inhalation of the vapours of degrading triaryl phosphate should be avoided as this can result in the short-term irritation of the throat and nose... The visible smoke from phosphate esters and the olfactory response to the presence of degradation products serves as a warning to avoid contact.'* [51]

BAe Systems advised customers in 2000 that a 1998 document from Mobil had *'conclusively demonstrated that, based on normal conditions of usage, it is not possible to inhale enough vapour or mist of engine oils containing TCP (such as Mobil Jet Oil II), or absorb enough through the skin to produce adverse neurological effects.'* [102,103] However the ExxonMobil studies have to date involved oral and dermal use of the product (cold) [97,99,100,101,104] and in 2010 ExxonMobil advised that it's 2003 studies (abstract published only [105]) involving oral dosing did not cause OPIDN and therefore it was concluded that as the oral route was considered the most severe, dermal and inhalation exposure would not cause OPIDN either. [106] Additionally Mobil advised that it knew little about the *'absorption, distribution, retention or metabolism of aryl phosphate esters after inhalation of mists or vapours'*, major routes of exposure in the workplace were dermal and or inhalation of mists and vapors and that *'for* *the purpose of evaluating risks the simplifying assumption that inhaled and ingested doses of aryl phosphate ester are of equivalent toxicity was employed.'* [104] Additionally Mobil has clearly advised that inhalation of engine oil in an aircraft is not considered *'normal use'.* [96]

A NYCO synthetic jet engine oil MSDS was changed in 2009 to reflect current research with the revised MSDS stating *'Product may decompose at elevated temperatures or under fire conditions and produce harmful gases or vapours. Vapours or mist of heated product may be harmful by inhalation... R 63.G3 Possible risk of harm to the unborn child. R 62.F3 Possible risk of impaired fertility… Respiratory protection… Wear an approved respirator in the presence of aerosols and when in contact with the heated product vapours.*' [107] The NYCO research into the toxicity of jet engine oils which tested 15 different organophosphates including TCP recently found that: [108]

- *'Commercial TCP (as used in most jet engine oils) presents a non-negligible potential of BChE inhibition in the test, comparatively with TOCP (tri-ortho-cresyl-phosphate), a potent neurotoxic, albeit this isomer is not detected in commercial TCP;*
- *TIPP (anti-wear used in 'Turbonycoil 600') does not present a significant improvement over TCP within the repeatability of this test;*
- *General rules between the chemical structure and BChE inhibition have been found, and specific organophosphates inducing a much lower inhibition have been identified.'*

The findings have led NYCO to file a patent application for *'new oil formulations having potentially an overall reduced neurotoxicity by several orders of magnitude comparatively to oils containing the same concentration TCP.'* The formulation will be free of phenyl-napthylamine. [108]

Adverse health effects acknowledged by many over the last 20 years include but not limited to:

- Aviation Medicine, RAF 1988: *'The oil may enter the cabin as a mist or vapour… exposure to oil vapour may cause irritation of the eyes and upper respiratory tract. Inhalation of the vapour also gives rise to systemic disturbances such as headache, nausea and vomiting.*

Exposure to oil mist can produce chemical pneumonitis from direct contact of the aerosol or liquid oil with lung tissue.' [109] *'If contamination of the aircraft cabin should occur, avoid the substance reaching exposed parts of the body and 'avoid inhalation' in the case of toxic gases and vapours ...breathe 100% oxygen as soon as possible'* and take all action to prevent leakage of contaminated air. [109]

- Mobil, 1990: *'It is reasonable to assume that a hazard exists by inhalation of mists or vapors of aryl phosphate esters.'* [99]
- USAF, 1992: Carbon monoxide has a much greater effect at altitude, e.g. flight at 6000 feet breathing 50 ppm CO in air results in a physiologic equivalent altitude of 12000 feet. [110]
- US FAA, 1998: *'JAR-E includes a unique hazard, "toxic bleed air".'* [111]
- Ansett, 1998: *'Short–term symptoms associated with odours that have been reported on the BAe 146 and other types are substantiated.'* [112]
- UK Government, 1999: *'The inhalation of mist (containing tricresylphosphate) which can be produced by high pressure systems, or direct contact with the skin, would be hazardous'* and *'TCP is toxic.'* [113]
- Allied Signal: *'A complaint for a smell is different than a complaint for smoke. Smell in the cabin is an indication that the ECS is lightly contaminated. Smoke is an indication of heavy contamination.'* [114]
- BAe, 2000: *'There is absolutely no doubt in our minds that there is a general health issue here. The number of people who have symptoms indicates that there is a general issue... It is very clear that there is an issue here which needs to be addressed. Our assertion is that it is a health and safety issue, it is not a safety issue ...With the weight of human evidence and suffering, which is quite clear, there must be something there.'* [3]
- Ansett, 2000: *'Short term symptoms are not uncommon.'* [115]
- Swedish Air Accident Board, 2001: *'During operation, oil and other contamination in the air that passes through the engine can accumulate*

in the air conditioning packs and cause a disagreeable odour in the cabin.' [116]

- UK Airline, 2001: *'DERA Porton Down and BAe Systems have clearly defined that oil leakage/fumes will cause serious discomfort but with no long-term health effects.'* [117]
- Aerospace Medical Association, 2002: *'VOCs can cause skin rashes, pulmonary symptoms and CNS symptoms ranging from mild to severe.'* [118]
- Rolls-Royce, 2003: *'Any oil leaking from an engine, entering the aircraft customer bleed offtake, is classified as HAZARDOUS.'* [119]
- German Regulator, 2003: *'Oil leakage… and oil residues… may lead to harmful contamination of the cabin air and cause intoxication of the flight crew.'* [120]
- US FAA, 2003: The forthcoming BAe 146 AD was considered to address *'the possibility of toxic odours and fumes from entering the flight deck or cabin area… which could result in the impairment of flight crew or passengers.'* [121,122]

- Airline, 2003: Acknowledged that it was unable to provide a safe working environment as it could not totally eliminate oil fumes when accepting it *'could not guarantee a pilot would not be exposed to fumes, the likelihood is that the pilot would be exposed to fumes and that therefore there is a risk of damage to his health.'* [123]
- UK CAA, 2004: *'In the event of oil leakage there is the opportunity, therefore, for the pyrolysis products of engine and lubricant/fuel to enter the cabin air supply and exert toxic effects on both passengers and crew.'* [124]
- UK CAA, 2004: *'Effect on workers producing tritolylphosphates is characterised by perivascular form of neuritis, and chronic gastritis with deficient secretion, toxic encephalopathy, hypothalamic syndrome, polyneuritis… Does not produce typical syndrome associated with cholinesterase inhibition… Tricresyl phosphate (mixed isomers) Can*

irritate the eyes on contact, can irritate the nose and throat, can induce nausea, vomiting, diarrhoea, stomach pain and loss of appetite... PAN: N-Phenyl-1- Naphthylamine: Suspect mutagen and carcinogen - tumorigenic in lung, thorax... Octanoic Acid and Decanoic Acid... Severe irritation of eyes and throat and can cause eye and lung injury. Cannot be tolerated even at low concentrations… 4,4'- Dioctyldipheylamine.. When heated to decomposition it emits toxic fumes of NOx.' [124]

- BALPA International conference conclusion, 2005: *'There is a workplace problem resulting in chronic and acute illness amongst flight crew (both pilots and cabin crew)... The workplace in which these illnesses are being induced is the aircraft cabin environment.'* [125]
- Airline, 2005: *'Smells and irritants from burning organic compounds from within the engines are known to produce harmful volatile organic contaminants.'* [126]
- TCP Manufacturer, 2005: *'TCP's used in aviation are only classified as Harmful by EU regulations and today, are much less harmful than those used previously.'* [127]

- UK Airline, 2006: If a noxious substance was released into the cabin air system, *'the substance is likely to be irritant rather than toxic.'* [128]
- CASA, 2007: *'Mobil Jet Oil II - Known to be harmful.'* [129]
- German Government, 2009: *'Does the German Government believe that inhaling of heated engine oil fumes is harmless for the health of crew and passengers?'* Answer *'No'.* [130]
- Australian Court, 2009: *'Smoke from pyrolysed oil can be hazardous to the eyes, mucous membranes and lungs.'* [131]
- ASHRAE, 2010: *'Typical commercial-grade TCP is a complex mixture of different isomers, all of which are neurotoxicants, with some more potent than others… These are not regulated by Title 14 CFRs and the only occupational health guideline available is for TOCP.'* [132]

An ASHRAE 1999 draft review paper states *'Crew are exposed more frequently than passengers and consideration must be given of cumulative and chronic* *exposures.'* [133] The final report stated *'Activity level, individual factors (e.g., preexisting disease, genetic predisposition, endocrinological functions), exposure to chemical mixtures, and exposure pattern (e.g., one-time, repeated, or chronic low-level) can all influence susceptibility to adverse effects of contaminants.'* [134]

SAE, while recognizing that airborne chemicals when present in the aircraft cabin air may impact comfort, health and flight safety, also found that *'incapacitation or performance degradation may potentially be aggravated by chronic low dose or prior contaminant exposure events.'* [10]

Exposure standards, generally based on the US ACGIH TLVs are inappropriate for application in the aircraft cabin. [20,35,109,118,135,136,137,138] Such occupational exposure limits are not available for all substances and apply to only one chemical at a time and do not reflect the *'actual situation in aircraft cabins'*, where mixtures of contaminants will be present along with effects of altitude on toxicity mechanisms. [10] Toxicity will also vary with differing routes of exposure and individual susceptibility factors, with *'concentration of contaminants, duration of exposure and frequency of multiple exposures'* all influencing symptoms which can range from reversible/ transient for mild irritants to irreversible such as for cancers and some CNS system effects. Other toxicology factors include: individual sensitivity based on genetic, pre-exposure factors amongst others and combined exposures may result in synergistic/potentiation effects. [10] However the US FAA and UK CAA are said to have '*certified engine bleed air quality based on 2000 ACGIH TLVs and BEIs.'* [10] Additionally *'public and occupational limit exposure limit levels differ, owing to the differences in nature of exposure, exposure duration and makeup of the exposed population.'* [10] Also public exposures may only cover outside air and not enclosed spaces. [10]

The UK CAA has advised their records show that in 2008 there were 12 pilots that had been accepted by the UK CAA to have lost their medicals attributed to (by the pilot and their doctors) cabin air with additional off work temporarily or who had allowed their medicals to expire. [139] The numbers obviously differ from the data in this thesis, as not all ill health will be directly attributed to cabin air exposures by the pilots or the UK CAA.

When asked if any risk assessment had been undertaken on the B757/767 fleet at British Airways, the Flight Manager Technical advised the concerned pilot that he was unaware if any specific risk assessment had been undertaken on the aircraft concerned beyond operating the aircraft in accordance with manufacturer's procedures, the well established SOP procedures in response to fumes/oil smell events and engineering workpacks. [140] Additionally, it was noted that there was much industry activity on this issue in recent years and the airline was participating in the Department of Transport study. When asked about specifically assessing risks to health when working with hazardous materials, the response given was that at present there was *'no evidence that crew or passengers are exposed to toxic chemicals or other hazardous substances... And therefore have nothing to assess the risk of.'* If a risk assessment was started there would be insufficient data to complete it and it would be meaningless according to the airline. On the other hand the airline Head of Health Services advised when questioned along the same lines that there was no scientific evidence that flying crew were exposed to hazardous levels of any toxic substances including OPs, which was the same view reached by industry research such as the COT inquiry and the airline was participating in other industry studies such as that carried out by the Department of Transport. [141] It was also suggested that with existing technology it was only possible to conduct cabin air sampling as part of a research program and previous studies undertaken by the airline during normal operations were *'reassuring'.*

A Boeing Component Maintenance Manual states that ducts may be sealed internally by using a resin mixture that is said to include *'Benzoyl Peroxide in tricresyl phosphate paste...'* [142] However the term *'TCP has generally been used rather loosely to describe triaryl phosphate preparations which may contain… a mixture of triphenyl phosphates, tricresyl phosphates, trixylenyl phosphates and trialkylphenyl phosphates',* each which may have various isomers which may differ considerably in their toxicity. [143] Triphenyl phosphate for example is widely used in polycarbonate resins or PC/ABS blends. [144]

7.2.3 Contaminated air exposures

The initial use of a large aerodynamic air compressor, from which compressed air could be *'bled in quantities suitable for cabin ventilation and refrigeration'* was viewed by the USAF in 1946 as *'fortuitous circumstance.'* [145] The use of synthetic oils rather than mineral oils was required due to the higher operating and bearing temperatures of turbine engines. [146,147] Soon after the development of synthetic lubricants the oil manufacturers recognized that turbine engines with higher compression ratios, and more power had forced temperatures of oils and bearings up requiring better oil compatibility with seals, if seal leakage was to be minimized. [148] The need for improved performance of the gas turbines consistently required the higher pressures and temperatures at the compressor outlet, necessitating specific design features to avoid rapid deterioration of the oil and bearings. [149] Very soon after the introduction of synthetic oils, gear and bearing fatigue, although influenced very much by the lubricant, were noted as a major problem. [150] This was despite the use of engine oil additives to improve oil oxidation and thermal stability. Thermal breakdown and deposits (sludge and coke) of the oil at high temperatures was early on thought to be caused by impurities and TCP or other phosphorus compounds, which are used as additives. [151]

During the 1950s, there was considerable industry awareness about the critical operation of oil seals used with a bleed air system and oil leakage. Problems associated with the use of engine oil-bearing seals pressurized with air that are responsive to variations in engine operating conditions were clearly recognized. [47] Additionally, the common use of labyrinth seals, were said to be reasonably effective when designed and operated appropriately, but could lose performance fast when seal wear occurred or during certain thermal or transient conditions. [152] Positive seals, such as carbon face seals used in hotter temperature areas require a more complex seal assembly and higher requirements of surface finish or flatness and in addition have a finite rate of wear. [149]

There is invariably some oil leak on start before the oil seal "beds in". Additionally, it was recognized that the common practice of using a positive air pressure gradient to assist in sealing oil in most main shaft applications was not a guarantee of zero oil leakage. [47] *'For labyrinth seals, reverse pressure drops must be avoided to preclude high oil loss'* [153] and it is important to have a larger differential leakage in the direction of fluid flow, particularly if there is a variation of pressure difference between both sides of the seal. [154] Standard rubbing contact face seals, on the other hand, under a wide range of pressure differentials, high sliding velocity and high temperatures, exhibited thermal instability which resulted in *'excessive wear and excessive leakage.'* [153,155] Other factors considered early on were the development and difficulties faced involving oil seals for operation at temperatures up to 1300°F (704°C) using a combination of materials which are compatible while operating in a variety of media. [47]

While the US military first used air drawn through the engine compressor in large quantities for *'cooling air'* for the Douglas XB-43, Lockheed P-80 and Convair P-81 in 1944/1945, [145] commercial airliners such as the B707 and DC8 up until the Convair 880 (1959), Convair 990 (1961) and VC10 (1962) all used turbo compressors rather than direct supply bleed air.

Clear recognition that the oil contamination problem is a design issue that extends back prior to the introduction of bleed air supply direct to the cabin, can be found in the following SAE statement: [10]

- *'Improved seal design. First-generation jetliner engine bleed air was contaminated with lubricating oil to the degree that turbo-compressors were necessary to provide the cabin air. Turbine lubrication seals have been improved such that concentrations of lubricating oil in bleed air is negligible.'*

While the military use of bleed air continued over the years from the mid 1940's, the direct use of bleed air in commercial aircraft commenced in 1955 with the SE210 Caravelle followed by a variety of aircraft in the early to mid 1960s including the HS Trident (1962), Boeing 727 (1963), BAC 1-11 (1963) Douglas DC9 (1965).

In the mid 1960s, air surrounding bearings and seals approached 700°F (371°C). [156] However, early on it was recognized that improved performance of the gas turbines consistently required the higher pressures and temperatures at the compressor outlet. While engine compressor temperatures are not readily available, some limited data is available. According to a Rolls-Royce publication, the continued drive for improved engine performance has seen clear trends in engine efficiency, power and safety. [157] In general, the intermediate (low pressure port) stage pressure compressor temperatures range from 50-300°C, while the high stage (high stage port) compressors range from 300-650°C according to Rolls-Royce and from 180°C to more than 350°C in other documentation. [157,158] Airbus has advised that the air is heated to very high temperatures by the engine compressor, typically 450-600°C. [159] The Honeywell ALF 502/507 (BAe 146/146RJ) engine using a single bleed system (high pressure compressor port only), reports a maximum temperature of 700°F (371°C) in the bleed air supply at the exit of the high pressure compressor. [160,161] Typical ALF 502/507 maximum temperatures of 350°C during part of the climb and initial cruise with APU temperatures around 200°C are reported. [162] Others report the ALF 502 engine as ranging from 100-400°C. [116] Boeing reports that the maximum high stage compressor compresses the air to 1200°F (648°C) and 430 psi for its B767 at take off. [163] Rolls-Royce reported temperatures for the B757 to be 310°C at maximum power take off. [162] Other industry sources report that a maximum bleed air temperature which would occur at take off power and the bleed switchover point to high stage bleed would vary dependant on the engine and conditions but could range from 316-427°C. [164]

High stage bleed ports, compressing and heating the air to higher levels, are used when the pressure from the low or intermediate stage is not adequate, such as at low engine power when the high stage is the only source of air at sufficient pressure to meet the needs of the bleed air system, such as taxiing, descent with the engine near idle and take off. The ALF 502/507 engine, however, uses a single air bleed extraction system utilizing a portion of high pressure air from the high pressure compressor. Therefore, this system eliminates the use of low/intermediate stage lower temperature ports for bleed air extraction. The single bleed air extraction manifold on the BAe 146 engine uses a very large percentage of air from the compressor for the cabin supply air, restricting airframe anti-ice procedures when the engine falls below set power levels. [165] The *‘massive bleed load’* ensures oil will exit in the bleed air and *‘increases the strain on the bearings and seals and reduces the amount of air pressure available to ensure the seals are seated.’* [165]

Since the DC-9 engine manufacturer *‘had taken special precautions to prevent oil leakage past the engine shaft bearing seals into the compressor inlet, the compressor bleed air was judged to be acceptable as breathing air.’* [64] To provide best economy and limit temperatures to which the air had been heated, air was withdrawn from either or both the eighth and thirteenth compressor stages. When only the air conditioning was in use, the pressure regulated valve operated at eighth stage temperatures of 330°F (166°C) or less and thirteenth stage temperatures of 550°F (260°C) or less. The use of air conditioning and ice protection utilized a mix of eighth and thirteenth stage air at 450°F (232°C). [64] By *‘proper switching’* it was possible to limit the bleed source to the eighth and thirteenth stage and *‘still avoid the use of air in the air conditioning system which had been heated to temperatures at which toxic oxidation products might exist in the event of an engine bearing seal failure.’* It was initially determined by reference to the engine manufacturer’s data that the thirteenth stage temperature limit of 550°F (288°C) was required in addition to the pressure limit alone, as air used for the cabin heated to above 550°F (288°C) would be encountered for a *‘considerable portion of the long range cruise envelope.’* The eighth stage air was used to the maximum extent possible given its *‘inherent savings in aircraft performance penalty when compared to thirteenth stage usage.’*

In 1956, Esso reported that *‘the occasional contamination of cabin air with thermally generated oil fogs’* introduced the question of toxic effects from thermal decomposition products. [48]

A 1962, Lockheed-Georgia Company report suggested that less than 100 cases of cabin air contamination had been reported on the C-130 A and C-130H aircraft with only six attributed to oil contamination caused by compressor seal leakage with the others attributed malfunction of the ducts and other equipment failures. [50]

In 1968, the Boeing Company produced a document regarding B737 Air Conditioning Engine Bleed Air Contamination. This remains unavailable for review. [166,167]

A Rolls-Royce report in 1969 recognized that evaporation loss of oil *'constitutes only a minor part of the oil consumption in Rolls-Royce gas turbines, the major part of the consumption representing loss of liquid oil arising from permissible leakage past certain seals, escape of mist or aerosol through breathers and losses incurred during filter inspections in service. These are made good by "topping up" the system with fresh oil.'* [149]

In a 1974 Garrett/Airesearch APU installation handbook (the original manufacturer of the APU on the BAe 146), it is noted that the least favourable location of the (APU) air inlet *'is an inlet located well aft at the bottom surface of the fuselage. Fluids likely to be ingested with this type of inlet include those that may be spilled within the aircraft fuselage, fuel-tank-leakage and vent-system discharge, leakage from the hydraulic system etc.'* [168] This is the location of the APU air inlet on the MD80.

A 1981 SAE report additionally recognized that *'any fluids used in the aircraft systems… can be an ECS contaminant'*. [73] *'These include lubricating oil, hydraulic fluids... They usually enter the ECS through the APU inlet... aircraft deicing can expose the APU or main engines to large quantities of glycol. This material will break down in the compressor and create irritating smoke which can quickly contaminate the entire ECS and cabin'*. [73] The report adds *'Where oil lubricated bearings are used, contamination of the oil can occur due to bleed air contamination leading to higher bearing failures. Air bearings may be subject to contamination damage from particulates and condensed fluids in the bleed air used to pressurize or cool the bearings'.* Like the 1974 Garrett bulletin, the SAE report noted APU inlets should not be located on the bottom of the fuselage where there is maximum exposure to amongst other things, fluid leakage. [73]

In 1985, Mobil Oil stated that as various airlines reported odor problems from time to time, Mobil Research and Development Corp. had conducted tests on *'some of the basic mechanisms relating to odor formation in jet engine oils. The results of the tests indicate odour generation is more likely to occur when oil is* *exposed to conditions that result in thermal degradation such as leaking past a seal into a compressor… reducing the amount of short chain acids formed during thermal degradation generally reduces the amount of odour.'* Changes to base stock formulation procedure resulted in reduced odour during thermal degradation in in-house testing. [169]

In 1990 Rolls-Royce stated: *'The approach adopted some years ago by Rolls-Royce was to recognize the fact that in the majority of instances where cabin air contamination was a problem, it was mostly associated with small leakages of synthetic lubricant from bearing seals etc.'* [170]

SAE reports the *'dirty sock odor is a more frequently reported description of odor in bleed air. This odor is known to be caused by butyric acid, butyraldehyde, and valeraldehyde.'* [11]

A 1985 Rolls-Royce service bulletin noted with regard to fumes and certification of the B757 RB211-535E4 engine: *'cabin air contamination has been experienced on acceleration from low power conditions during the B757 flight certification programme.'* [171] The source of the contamination was identified as an oil leak from the front bearing housing rear oil seal. A 1984 service bulletin also raised the issue and concerns of health hazards of asbestos being used in air seals. [172] Further service bulletins relating to Rolls-Royce modifications to the RB 211-535 engines were sighted by the author relating to oil leakage and cabin odours [173] as well as:

- 1991 SB noted contamination of the bleed air ports (HP2, HP6) resulting in oil odour in the cabin and specifically that *'a number of operators have reported high oil odour levels, resulting in several engine removals.'* [174]
- Front bearing housing oil seal leakage was noted with the RB211-22B and 524 engines involving the front and rear oil labyrinth seal leakage under SB 72-4862 in October 1977.
- Carbon blockage of bearing chamber scavenger strainers leading to high oil consumption, HP/IP compressor, IP/LP turbine oil wetness, high vibration was linked to SB 72-5528 for the RB211-22B and 524 engines in June 1979.

- A Rolls-Royce Notice to Operators: [RB 211-22B and 524 (all marks)] was published in 1983 stating *'generally experience has shown that oil leakage within the core engine, from the LP and IP compressor front roller bearing or location bearing chambers, can, but does not necessarily cause, the cabin odour.'* [175] Further notices to operators were subsequently issued for various engine models involving oil leakage and cabin odours. [176,177,178]

In 1985 PSA, airlines nominated to change it's entire MD-80 and BAe 146 fleet to use MJO 254 as it had experienced significant costs associated with significant carbon deposits forming in the seal areas of the JT8D-200 engines used on the MD-80 aircraft with Exxon 2380. It was assumed the carbon deposit problem would be eradicated with the dedicated use of MJO 254. [169]

A 1986, Lockheed internal service news report advised that operators of Hercules aircraft had *'occasionally noticed the odour and sometimes the eye and nose irritation, associated with engine oil fumes being introduced into the air conditioning system.'* [179] Experienced Hercules aircraft crews were reported to be aware that the 501/T56 developed under certain conditions a variety of 'nuisance-type static oil leaks' that would force the oil into the bleed air system on start and find it's way into the air conditioning system. The *'undesirable effects of this contamination'* could be minimized by making minor changes in the start and run-up sequence. Such procedures were said to be an effective way of keeping the *'unpleasant and irritating oil fumes'* out of the cabin air supply. Additionally bleed air system contamination by engine oil *'could occur at any time as a result of an internal oil leak.'*

A 1987, McDonnell Douglas aircraft DC9 service bulletin revealed that several operators had reported smoke in the cabin related to hydraulic fluid leakage into the air supply system. If not corrected, this could result in passenger or crew discomfort and possible delay and or cancellation of flight. [180]

A respected aviation medicine text produced by RAF personnel in 1988 reported that: *'By far the commonest cause of toxic contamination of the cabin air of a fast jet aircraft is overheating of a bearing or a failure of a seal of a bearing of a moving part in the environmental control system, which allows* *lubricating oil and/or the products of heated lubricating oil to enter the cabin air-supply system.'* [109]

Alaska Airlines wrote to McDonnell Douglas in 1996 advising that it had experienced *'several incidents of reported fumes or odors in the MD-80 aircraft cabins during normal flight and ground operations. The fumes seem to originate from leakage of fuel, engine oil or hydraulic fluid in either the wheel well or the tail compartment. Leaking fluids, mists or vapors are finding their way into the APU inlet and are being distributed through the air conditioning systems and into the cabin causing reports of a "burnt oil smell".'* [181] Despite a number of modifications to minimise and divert leaks, the airline advised it was discouraged that in a recent hydraulic fluid leak event in the tail compartment, in an aircraft that had undergone specific modifications to rectify this problem, the crew reported adverse effects, were hospitalized and advised they had CO in their systems. The airline recognized that it could not *'completely eliminate fluid leaks on an aircraft'*, although it had taken a number of steps to minimise leaks and would continue to do so. The airline asked *'what must we do to prevent fluid leakage from influencing the cabin environment and coming in contact with and affecting people?'* In response McDonnell Douglas advised Alaska Airlines that *'Douglas shares Alaska's concern on contaminates being ingested into the aircraft cabin.'* Douglas advised that it was holding meetings with its propulsion and environmental systems engineers to *'determine a root cause.'* [182] It also advised that it was *'investigating measures to preclude recurrence of fumes/odors in the cabin and to develop a method of detecting any residual contaminates after the aircraft system has been purged.'*

In 1998, Airbus undertook a cabin air quality and temperature sampling program on Air Canada A320 aircraft based on reports of discomfort within the cabin. [183] Reports of *'hot smell or oil smell'* with the origin of the smell attributed mainly to ECS contamination were caused by APU oil leakage. To eliminate the smell, it was strongly recommended that the airline carries out ECS decontamination according to maintenance procedures. Measurements revealed that gas concentrations within the cabin were well below the limits required by the airworthiness authorities and that *'based upon these conclusive results, Airbus Industrie confirms that cabin discomfort are not attributable to* *any deficiency within the air conditioning system.'* A similar program had taken place 4 years earlier that found CO, CO_2 and O_3 were not the cause of passenger and crew complaints on the A320.

In 2000 the US FAA issued a Special Airworthiness Information Bulletin (SAIB) advising that the Allison Engine Company AE 3007A series engines (Rolls-Royce Allison) installed on the EMB-135 and EMB-145 series aircraft amongst others, were subject to a variety of engine inspections and modifications. [184] The improvements were developed for engine caused cabin smoke or odor events produced by oil leaks or fuel vapors.

Various Boeing service letters addressing the smoke and burning odour issue have been published. [185] Bombardier issued a service letter in 2004 for it's Dash 8 Q100, 200 and 300 series aircraft related to ECS contamination. [186] As several operators had reported *'unpleasant oil smells or other odours as a result of contamination of bleed air from the engine or APU entering the ECS'*, Bombardier advised operators of a procedure to purge the air conditioning ducts after bleed air contamination, or reported smells or fumes. [186] British Airways, as an operator in 2010, published a flight admin notice regarding *'odour/smoke/fumes reporting.'* [187]

An Operators Engineering Bulletin (OEB) was issued for the Airbus A340-500 (circa 2008) series aircraft titled *'engine bleed air off to prevent oil smell in the cockpit/cabin.'* It is applicable to *'A340-500 aircraft with engine affected by the oil smell issue.'* The bulletin was raised as some operators using the A340-500 Rolls-Royce Trent 500 engine had reported cockpit and cabin oil smell and/or fumes leading to some flight crew using oxygen masks and causing some passenger discomfort. Most of the oil smells/fumes were attributed to oil leaking from the rear of the front bearing housing (FBH) at low thrust power settings. The leaking oil goes to the IP compressor and finishes in the HP compressor where it burns, causing the oil smell and fumes during low power setting flight phases. The smell/fumes emanate from the air conditioning system which takes bleed air from the HP compressor. Only after some time at high power setting, the oil burns off completely and the engine bleed can be considered free from risk of fumes/smell. Rolls- Royce was said to be investigating the issue in order to find a fix. It also advised that a *'significant number of engine removals are* *driven by cabin odour'* with some operators more affected than others. [188] The *'primary cause of cabin odour events is oil leakage through the FBH air/oil seal due to inadequate sealing margin'* with various modifications highlighted. [188] The *'sniff test'* was listed as part of the diagnostic test procedures for the engineering division.

A review of all airframe and engine model service bulletins and service information leaflets /letters is required as numerous more SBs and SILs were cited by the author for various engine types.

An undated Allied Signal/Garrett Auxiliary Power Division operating document referring to US FAA Type Certificate Orders (TSO) states that *'contamination, if added as a result of air passage through the unit, shall not cause bleed air from the unit to be harmful or unpleasant to the cabin or cockpit occupants of an aircraft.'* [189]

A 1996 Allied Signal (APU manufacturer) publication shows that Allied Signal approved MJO 254 without specific testing on the 85 series APU with some seal elastomers found to be incompatible with the engine oil MJO 254. [190] Elastomer compatibility was dependent upon exposure temperature and seal type with dynamic applications being more severe. Causes of leakage on the 85 series APU were identified as leakage at the face/rotor interface due to oil coking on the higher-time seals and deterioration of the secondary o-ring seal on the lower-time seals with observations similar for the compressor inlet seal and the accessory gearbox output pad seal. While leakage was greatest with the use of MJO 254, leakage also occurred with other oils including Exxon 2380, MJO II and Castrol 5000. [190] A history of APU seal leakage with increased APU seal leakage removals put down to longer (APU) on wing times, led to a program of engine seal improvement to address seal leakage problems with known causes of seal face coking, imitated in the late 1980s. [191] Allied Signal later reiterated it was *'committed to provide seals compatible with all approved lubricants'* and an Allied Signal/Mobil team was established to investigate further with a variety of seal improvement actions identified. [190] Actions included change of inlet seal types; seal upgrades; carbon material upgrades, improved carbon face loading and tracking, elastomer upgrades to current materials, turbine seals and bearing redesign amongst others, however the seals would still be subject to coking from high temperatures. While excessive seal swell, compression set, cracking and break-up of the seals was evident in the 36-150 series APU as well as the 85 series, Allied Signal issued a preliminary Airline Field Service Notice cautioning operators using 85 series APU use with MJO 254 that this combination could *'lead to premature removals for seal leakage or bearing distress.'* [191]

In 1988 TCP was found, in RAAF aircraft. [192] TCP has been found in aircraft on at least 15 other occasions as shown in Chapter 4. This has included TCP found in the cabin air, ducting, filters, swab samples in addition to aircrew blood.

The 2004, UK CAA *'Cabin Air Quality'* paper found that the fumes from engine oil leaking into the bleed air system and hence into the cabin air supply, is the *'most likely cause'* of the incidents and no weight of evidence indicating otherwise was found. [124] The ducts examined *'were contaminated with a carbonaceous material containing chemicals entirely consistent with the pyrolysis products of aircraft engine oil'*, with TCP isomers found at higher levels than in the parent oil. [124] The AAIB reported in the same year that: [193]

- *'During investigation into "smells" on a BAe 146, it was discovered that the four air conditioning sound attenuating ducts in the rear fuselage were contaminated with a black substance and had a distinct odour. Replacement of the ducts cured the smell on the affected aircraft. The contamination on the ducts was swabbed and tested, and the results revealed that it contained used engine oil but fuel, deicing fluid and new engine oil were not discovered in the sample. There was, however, a negligible amount of hydraulic oil. The engine oil was identified as used Exxon 2380, together with a small amount of Mobil Jet II. The aircraft operator had not used Exxon 2380 since 1997, having replaced it with Mobil Jet II at that time. As a result, a Service Bulletin, ISB 21-156, was issued by the manufacturer to inspect for, and replace, contaminated ducting.'*

In 2004, British Airways held an odour meeting regarding the B757 RB211-535E4 engines. [194] In addition to oil smell reports listed for the period 1999–2003, a number of work packages were published on engineering actions to take place after such reports as well as various modification programs. Key modifications included corrective actions to: the fan shaft to LP roller bearing inner race leakage; front bearing housing flange leakage; LP location bearing flange leakage and 46 bolt flange leakage.

In 2004, Boeing advised that that the B7E7 (787) (Figure 7-1) bleed free engine selection was *'one step forward'* in dealing with the contaminated air issue. [195] In 2007 Boeing stated *'the Boeing 787 will have a no-bleed architecture for the outside air supply to the cabin. This architecture eliminates the risk of engine oil decomposition products from being introduced in the cabin supply air.'* [196]

Figure 7-1: Boeing 787

Additionally Boeing B757 maintenance manual procedures include the removal of air conditioning system oil contamination. [197] The manual reports that *'oil fumes and the smoke from an APU/engine failure can get into the airplane cabin and cause contamination of the conditioned air. The APU is the most likely source of the smoke or odours. Any APU failure can release oil into the air conditioning system. Oil, glycol or hydraulic fluid ingested into the inlet of the APU is another possible source of the contamination. When oil enters the pneumatic and/or air conditioning system, it tends to accumulate in the heat* *exchangers or the precoolers. The oil, hydraulic fluid, or the glycol vaporizes at a higher temperature and enters the cabin.'*

The UK AAIB reported that *'service experience shows that, mostly, on aircraft types fitted with turbine engines, because the conditioned air is sourced from the engine compressors, it is vulnerable to contamination from engine oil leaks that allow oil to enter the compressor air path.'* [198] The AAIB also advised that: [193]

- *'Whilst the industry seeks to reduce to a minimum the incidence of such events, there is a general acceptance that fume events will occur, from time to time, on all jet powered transport aircraft.'*

In 2005, the UK Government acknowledged that there are no exposure standards that apply to the synergistic mix of chemicals that would be exposed in the aircraft environment. [199]

A UK airline in its operations manual discusses the use of the APU for air conditioning before main engines start. [200] The manual advises to *'use both packs from approximately 10 minutes before boarding. Thus by the time the passengers arrive, the temperature control will have stabilised and any contamination will have been revealed.'*

DHL operating the B757 advises that *'it is not unusual to experience a low concentration of fumes' after engine start, during taxi, after take off, particularly at full power, top of descent and taxi in… if such fumes become apparent during any of these phases of flight and then dissipate, do not report the occurrence, it is normal.'* [201] The UK CAA accepted this view was satisfactory. [202]

'WorkCover' NSW who considered the issue in detail, concluded that '*Employees/Persons may be exposed to risk to their health and safety from contamination on the flight deck of Qantas aircraft*…' *As a consequence, WorkCover has issued Qantas with an "Improvement Notice".'* [203]

As recently as June 2010, a confidential report raised under the NASA Aviation Safety Report System sent to Embraer provides details submitted by an EMB 190 pilot about fumes smelt on the ground over several sectors suspected to be a 'ventilation problem allowing either burnt or burning oil fumes or engine exhaust to enter into the cockpit/passenger cabin ventilation system. [204] The pilot reported that the EMB-190, has a more noticeable smell of burnt oil, or exhaust fumes than the EMB 170/175. On the 5th of 6 legs the pilot reported that all the crew were reporting adverse symptoms and he personally was experiencing: headaches red and burning eyes were red and burning, an unusually dry nose and the taste of blood in the back of the throat lasting 2 days. The pilots noticed they were having difficulty concentrating, particularly under high workload, their thought process was starting to slow and they noticed each other making unusual mistakes. Other general symptoms experienced during the short period operating this specific type of aircraft included: eye lid twitching, hand shaking and cramping in the frontal lobe region of the brain during the day of the fume event and day after. The pilot went on to state: *'I recommend installing those stickers in the cockpit that turn color when chemical, carbon monoxide, etc. is detected, or have some type of portable air quality sensor in every cockpit to alert the flight crew of odorless, and identifiable odors before they become a health and safety hazard.'*

The NASA reporting system, however interpreted the pilot's concerns as relating to 'this model Embraer is uniquely susceptible to ingestion of exhaust fumes from the APU and/or its own turbine exhaust,' as distinct from the clearly mentioned terminology of oil fumes.

Many industry bodies are now officially recognizing that contaminated air occurs include but not limited to:

- ASHRAE: *'The APU inlet and engines can potentially be an entry point for hydraulic fluid, fuel, oil and deicing fluid.'* [134] Such incidents such as worn oil seals or mechanical failures within the APU or engine are minimized by proper design, operation and maintenance.
- NRC: *'Oils and hydraulic fluids can leak into aircraft cabins… If oils and hydraulic fluids enter the aircraft cabin, they will adversely affect cabin air quality.'* [205]
- EASA: *'The vast majority of fume events are associated with an abnormal leakage of engine or APU lubrication fluid (aviation engine oil).'* [39]

- EASA: *'The issue of cabin air contamination has been triggered based on engine or APU oil seal or bearing failure, engine or APU maintenance error/irregularities, or design deficiency, engine or APU oil, hydraulic fluid, fuel, de-icing fluid and the corresponding pyrolysis products may contaminate the bleed air, which then enters the cabin air supply and can be inhaled by the aeroplane occupants.'* [39,206]
- COT: *'Association between oil/hydraulic fluid smoke/fume contamination incidents and acute health symptoms indicate an association is plausible.'* [207]
- SAE: *'Aircraft fluids such as engine oil, hydraulic fluids and deicing fluids can be ingested by engines and APUs. Lubricating oils can be directly introduced into cabin air by leakage from engine/APU bearing seals upstream of the bleed air extraction port... It is possible in some designs that lubricating oil may leak at greater rates when an engine or APU is started and seals not yet at operational pressure and temperature or during transient operations such as acceleration/deceleration. Some systems rely on internal air pressure to maintain the sealing interface. When an engine shuts down this interface is opened, possibly allowing some oil to exit the oil wetted side of the seal. Upon engine start-up, this oil is entrained into the air entering the compressor of the engine. The seal interface is again established when the engine internal air pressure returns to operating norms.'* [10]

Some components associated with leakage events such as air ducts are non cleanable and must be replaced when contamination is excessive, such as *'acoustic ducts and mufflers which contain fiberglass insulation which can trap contaminants and later release them into the conditioned air stream.'* Other procedures to flush or burn out contaminants include pack burns. [10] Allied Signal recommended pack burns used to remove (oil/hydraulic fluid) odours from the air supply system be discontinued on a regular basis in at least 1997, as levels of hydrocarbons approaching the recommended allowable limits could occur and continue for some time after the procedure. [135,136] BAe Systems in SIL 21-45 in 2000 advised the cessation of pack burns (originally recommended in SIL 21/7 -1984) so as to *'burn oil contaminants from the ECS* *packs by elevating the conditioned air delivery temperature*.' [208] ASHRAE reported that a *'pack burnout may temporarily remove odors but will not clean the surface (that is, the secondary source) of contaminants because the temperatures are not high enough to remove oil or hydraulic fluid components, leaving a residue of tars and other hydrocarbons.'* [134] Therefore such pack burnouts *'must not be conducted when passengers or crew are present, due to potential release of contaminants in the cabin.'* [10,134]

A 1999 ASHRAE draft report advised *'When an oil leak from an engine or APU is repaired, the system downstream must also be thoroughly cleaned to eliminate unintentional introduction of contaminants into the cabin… there is no effective way to adequately clean bleed air ducts in situ once they have become contaminated with oil breakdown products. Adequate cleaning requires removal of the ductwork to wash out oil products… with cleaning typically reserved for major maintenance checks'.* [133,209] The final 2007 ASHRAE report was more reserved in it's wording suggesting *'the APUs and ducts, from system inlets to the airpacks, should be inspected following ECS contamination, and if a buildup of residue is noted, then systems should be cleaned (e.g., high pressure washing, steam cleaning). At least as often as at major service intervals, a total system cleaning should be considered.'* [134] Another rarely recognized issue involves fume defect recognition. ASHRAE draft guidelines indicate that *'line maintenance staff generally rely on visual inspection of aircraft systems and on assessing odor in the cabin or flight deck. They have limited ability to troubleshoot internal oil leaks and sense of smell is an unreliable indicator of exposure because it is easily compromised.'* [130]

There are varying views on how contaminants are regarded. For example Airbus advises that *'Airbus aircraft are designed to avoid cabin air contamination in normal operating conditio*ns.' [210] Rolls-Royce in 2005 advised that bleed air quality was addressed upon engine certification, while in service, *'correctly maintained and operating Rolls-Royce engines comply with all applicable certification requirements.'* [211] According to Rolls-Royce the aircraft operating manual explained the steps to be undertaken when bleed air contamination occurred. Alternatively, prevention of unwanted compounds entering the bleed air was seen by Honeywell in 2003 as not possible, with treatment to take place where possible. [12] Honeywell also suggested that innovative designs should be considered such as zero bleed (including vapour cycle refrigeration), supplementary bleed/enhanced bleed management, amongst others, with treatment options including use of air quality devices, higher recirculation air ratios (dilutes unwanted compounds) and integrated sensors and diagnostics for fault trend monitoring and isolation.

However, some manufacturers have introduced bleed air contamination and oil detection ground based kits. [212,213,214,215] Development of kits had been ongoing since the early 1990s as acceptance criteria of the engines has been based on the ability to smell an odor as well as visual keys of oil leakage from smoke or oil consumption. [215] For example, Airbus in 2008 reported that with regard to cabin odours VOC/Ozone converters and HEPA/VOC recirc filters, which were optional equipment to improve cabin air quality, were not utilized to remove oil fumes with the former not tested for oil/fumes and suitable for gaseous contaminants only best for the airport/ramp environment, while the later was used to remove general cabin odours such as bio effluents, meals, beverages. [216] However, these were deemed to potentially reduce odours and therefore mask smaller leaks at early stages with the risk of complete ECS system contamination in the long-term. Therefore, Airbus did not consider them as *'a proven mitigation against oil contamination of the bleed air.'* [216]

In 2010, the Irish Accident Investigation Unit advised: *'Poor cabin air quality has been an on-going issue in commercial transport aircraft. A common cause is leaks in the engine or APU oil seals that permit oil, oil mist or oil vapour to enter the airconditioning system.'* [206]

7.2.4 Reports about adverse effects in crews

While toxicity concerns clearly existed relating to the use of breathing air from the engine compressor and the use of synthetic lubricants in the 1950s and 1960s [44,45,47,48,50,57,69] and there were concerns that crashes may have occurred attributed to engine bleed air contamination, resulting in the Navy requiring 100% oxygen to be used throughout flight. [109] There was historical clear recognition that engine oil seal designs were not sufficient to keep the air supply free of contamination and that bleed air contamination was a threat. [10]

However, the earliest clear case found in the literature of toxicity following jet oil exposure and adverse health problems in aircrew was reported in 1977. [71] A previously healthy member of a military aircraft flight crew was acutely incapacitated during flight with neurological impairment and gastrointestinal distress. His clinical status returned to normal within a day. The aetiology of his symptoms was related to an inhalation exposure to aerosolised or vapourised synthetic lubricating oil arising from a jet engine of his aircraft. The report stated that the *'plastic odour'* on the flight deck (related to engine oil) was not infrequent, had specifically come about through the advent of *'synthetic jet oils'* and that investigation into the potential hazards of inhaling the oil fumes *'is definitely warranted'.*

Further published studies of exposures in aircraft included a 1983 study of 89 cases of smoke/fumes in the cockpit in the US Air Force, [38] and two other 1983 studies of cabin crew linked to oil inhalation and dirty socks smells. [217,218] Other studies include a UK B757 pilot survey; [219] a 2005 study; [220] a 2006 UCL study [221] and a 2009 US FAA funded study. [222]

Risks to health from exposure to jet oil emissions specifically on the BAe 146 were reported in a 1998 study of BAe 146 aircrew s in Canada over a four-month period; [223] an Australian 2001 study; [224] a 2002 survey of predominantly BAe 146 aircrew reported similar findings in a group of fifty aircrew respondents [225] and a 2005 study of BAe 146 crew in Australia [226] and a 2009 study of pilots in the UK (outlined in Chapter 4).

7.3 BAe 146/RJ case study

The history of the development of the BAe 146 is interesting with the original late 1960's HS 144 aircraft design using 2 Rolls-Royce Trent engines unable to proceed following the 1970 bankruptcy of Rolls-Royce. [227] Consequently, the use of the Avco Lycoming ALF 502 was accepted and the design changed to what became the HS 146. The introduction of the HS (BAe) 146, was given the official go ahead in 1973 by the then Hawker Siddley with £46 million of UK Government funding matched by Hawker Siddley. With the world oil crisis, costs soon escalated and the HS 146 was cancelled in 1974, as it was seen as not financially viable. However, with the newly elected labour Government, the Government provided funding to keep the project *'ticking over'.* In April 1977 the state owned British Aerospace came into being as the former Hawker Siddley was nationalised and there was considerable pressure to recommence the BAe 146 project for the sake of British jobs. In July 1978 the announcement was made that the project would recommence. BAe's Chief Executive from 1986 to 1989 insisted the decision to go ahead with the 146 was purely political and made by a labour peer to keep jobs at Hatfield. In the end almost 400 aircraft were manufactured between 1978 and 2002 providing a great many British jobs. [227]

The ALF 502 engine was made by Avco Lycoming (division of Avco Corporation), which was later purchased by Textron with the company renamed Textron Lycoming. In 1995 it was sold to Allied Signal, which was merged with Honeywell in 1999. The ALF 502 engine was based on a design whose engine core (T55) came from the Chinook helicopter and was obtained at a *'very competitive price'*, utilizing 4 engines instead of the usual twin engine arrangement used on shorthaul aircraft. [227] The ALF 507 engine, a slightly more updated and powerful engine than it's predecessor, has been utilised on some BAe 146- 300 series aircraft and the BAe 146/RJ fleet.

Documentation highlighting awareness of the contaminated air problem on the BAe 146 and RJ can be broken down into official general industry documentation and specific operator or other documentation. Both will be reviewed and must be looked at closely to understand how both sets of data show how awareness and documentation of the contaminated air problems led to official actions. Selected examples only will be highlighted.

7.3.1 Early BAe 146 industry documentation/awareness

A 1985 Mobil Oil manufacturer letter to the engine manufacturer indicating Mobil had previously discussed with Avco Lycoming (engine manufacturer) the *'early problems of cabin odor on the BAe 146/ALF 502'* and references problems of cabin odour on the BAe 146/ALF 502 that were reported by other airline operators and occurred *'from time to time'*. Mobil noted *'odour generation is more likely to occur when oil is exposed to conditions that result in thermal degradation such as leaking past a seal into a compressor… reducing the amount of short chain acids formed during thermal degradation generally reduces the amount of odour.'* Changes to base stock formulation procedure for full esterification results in reduced odour during thermal degradation in in-house testing. It was hoped this change (MJO 254) would reduce the problem of odours being experienced on Pacific Southwest Airlines (PSA) BAe 146 aircraft. Hatfield (BAe) advised there were less odour problems with engines using MJO 254 than those using other oils. [169]

The Mobil 1985 letter to Avco Lycoming, was referenced by Textron Lycoming in 1992 to Ansett suggesting that Mobil Jet Oil 254 *'reduces carbon build up and as an added benefit to reduce cabin odors caused by seal leakage.'* [228]

BAe viewed that the airworthiness regulation 25.831(c) (eliminating harmful and hazardous contaminants from system) was met, given that the ALF 502 engine embodied design features to prevent oil from entering the core airstream in the event of a critical seal failure. [13] This included *'No. 1 and No. 2 bearing having higher air pressure on the outside of the seal, so that air leaks in rather than oil leaking out.'* With regard to the APU source of contamination, oil from a damaged or cracked compressor seal carbon was minimised by design features. Any leaks would be extremely small with *'infrequent'* events indicated by a *'slight non-toxic odour in the aircraft cabin.'* [13]

A sales promotion brochure for the BAe 146 advised that *'air bearings are employed in the cold air unit, precluding the possibility of oil fumes in the cabin.'* [229] Meanwhile, an ALF 502 engine training manual states that the engine *'bleed air is free of engine generated noxious-toxic, or irritating substances and contains no objectionable odour.'* [161]

Despite the contaminated air awareness problem that surfaced from the BAe 146 aircraft's first year in operation, the first non official evidence of awareness of the problem can be seen in a 1986 Australian Ansett BAe 146 incident report. [230] The captain reported *'Prior to departure crew advised of possible cabin smoke associated with APU bleed air for air conditioning. With pax on board, cabin began to fill with irritating smoke. Both crew and pax showing discomfort… MEL 49-50-1 raised… use of No. 4 bleed air on for take off and landing… Cabin filled with smoke again…'*

The BAe production flight testing manual, Issue 5, 1989, states under the heading: [231]

- *'3.6: Engine Smells: An engine that can be positively identified as causing a smell should be rejected. An engine smell should not be confused with the smells emanating from new ducting or catalytic converters that are habitually present on the first few flights. The following technique should identify a smell as coming from an engine.*
  - *3.6.1: Perform a series of climbs from about FL150-300 using individual engines as the sole source of conditioning air.*
  - *3.6.2: if a smell is present when one engine is supplying air, but not when the adjacent engine is supplying air through the same pack, it can be assumed to be emanating from the engine and not from a contaminated pack.'*

The manual contains a *'company confidential'* clause advising that the aim of production flight testing is to find and rectify defects in production and that occasionally design defects are revealed for the first time during the production flight testing. [231] In order to *'avoid overloading production resources and to prevent the prejudicing of future discussions with the customer'* certain procedures were to be followed when recording aircraft defects. These involved: pursuing design queries to establish that a defect existed before recording it; only recording items that *'are build defects that are capable of being cleared to the satisfaction of the customer'*; *'defects in design should be actioned through* *other channels than the pilot's Defect Report*'; *'in contentious and/or subjective areas… seek advice before formally recording the snag.'*

By the late 1980s and early 1990s, there is documentation showing airline operators were experiencing problems. Air UK reported problems on the BAe 146 with the comment: *'Our problem stemmed from contamination of air conditioning ducts. APU oil smells in cabin and fungi in galley/toilet areas (1989-90).'* [232] A 1992 BAe Aerospace letter to Allied Signal notes that *'for some time now',* operators of the BAe 146-300 had been experiencing unpleasant cabin odours which are caused by oil leakage from *'your Auxiliary Power Unit.'* [233] The BAe letter advised that it had received complaints at senior management level *'within the last seven days'* from Ansett and Dan Air regarding the suitability of the Garrett APU and oil fumes and the lack of credibility of the Allied Signal engineering management. This problem was *'First raised to Garrett at the Operators Conference in Perth in 1989.'* [233] The problem first identified in December 1991 by Ansett was said to have extended back another 18 months to mid 1990 according to a report from the Australian Bureau of Air Safety. [234] Ansett New Zealand was also suffering problems from at least 1992 with oil contamination. [235] This was confirmed by Ansett correspondence to Dan Air noting that Ansett was working intently with Garrett and BAe to find a solution and that Ansett New Zealand was experiencing the same problem. [236] Ansett advised the smells had been with it for well over a year and caused industrial problems with crews and a negative passenger reaction, which it couldn't *'continue to live with.' [*236] In 1992, Dan Air advised Ansett that it too had *'suffered the 'smelly socks' smell'*, which had been a source of pilot, cabin crew and passenger complaint. [237]

A similar memo was raised by the Dan Air BAe 146 Fleet Manager, in March 1989. It stated *'In recent weeks we have had three of four instances of smoke in the passenger cabin on first reintroduction of air conditioning after starting engines. On these occasions a 'B' snag was already in the technical log… This problem is usually caused by oil contamination of the air ducting…'* [238] An Ansett medical consultant noted in 1996 that reports of *'foul smelling odours associated with some physical symptoms amongst flight crew and passengers have been reported sporadically from airlines operating this aircraft throughout* *the world.'* [239] Notes from an Ansett odour inquiry meeting note that Ansett new Zealand first detected the problem in early 1990, while Air BC, Swiss Air, Cross Air also reported to have experienced the cabin odour problem. [240]

In 1991 an internal British Aerospace BAe Complaint or Difficulty Report raised by Bruce Rogers involving a Dan Air BAe 146-300 incident on G-BTNU on 10 February 1991, was sent to the head of fluid systems requesting an urgent reply. [241] The report in part stated: *'note 1: Can Hatfield provide a definitive statement on the medical implications of fumes/smells in the cabin (Dan Air cabin crew have complained of headaches and nausea).'* An interim response on 27 March 1991 notes; *'The problem of APU produced odours in the cabins of aircraft G-BTNU and G-BPNT is being urgently investigated by BAe.'* [241] The author of the original complaint report, Bruce Rogers then made the following comment over two years later on 10 March 1993: [241]

- *'Thank you for the information on coalescers filters etc. Let us hope they are the final solution. I would like to refer to my note 1 on the original report and ask if the head of fluid systems has provided the urgent reply... Although Dan Air are unfortunately 'extinct' I feel the questions and its answer still has relevance and interest to other operators. The Health and Safety Executive seem to take a lot of interest in smoke and fume inhalation. Here we have a reported case of headaches and nausea and despite a 2 year wait we still have no statement on Health and Safety. Can you please hasten an answer on this point.'*

The February 1991 internal BAe question regarding health questions was sent on to Allied Signal, the APU maker. A response a year later simply referenced the 1983 US FAA and NTSB air quality investigations advising the heated oils could breakdown at elevated temperatures, however the reports had not shown this was the case as temperatures and low compressor ratios (on a turboprop engine tested on the ground) did not cause this to occur and were therefore comparable to the Garrett APU used on the BAe 146. [242]

A Dan Air (UK airline) memo dated 11 June 1991 is a partial summary of the fifth British Aerospace Operators Conference. [243] The memo notes; *'We raised the question regarding passenger cabin smells/odours that have plagued the BAe 146-300 aircraft, which have the Garrett 150 APU installed and which it* *is believed is responsible for these smells/odours.'* Dan Air attendees read out the following points to those attending the conference (in brief):

- Very significant and serious problem equal in magnitude to the technical problems in previous years;
- Numerous verbal and written complaints from passengers;
- Losing passengers as some transfer to other carriers when told they were to fly on the BAe 146;
- Concern over the possible medical implications associated with the smells/odours. Cabin staff had complained of headaches, nausea, sore throats. Problem referred to company doctor;
- '*That there was a large cost implication attached to this problem. BAe and Garrett were advised of the high maintenance man hour expenditure on this matter to date in removing and refitting APUs, carrying out APU bay sealing modifications etc., all of which to date have been to no avail. BAe and Garrett were asked who was going to 'pick up' these costs';*
- *'BAe and Garrett were asked who was going to pay for the problems being seen with the cold air units in the air conditioning system (e.g. air bearing failures and nozzle erosion) - caused by oil contamination. They were also asked who was going to pay for the conditioning pack cleaning and who would 'pick up' the costs of the passenger claims for cleaning of clothes';*
- Other BAe 146-300 operators also experiencing same problem and *'East West Airlines of Australia were equally as vocal as the DAS attendees on this matter';*
- East West Airlines representative advised that, *'They had received a very bad passenger reaction to this problem and went on to advise that after take off (on all flights) the captains were making a PA announcement to passengers and apologising for the 'sweaty socks' smell'';*
- *'BAe and Garrett specialist responded to the operators complaints – They were left in no doubt at all that this was a very serious situation.*

Both BAe and Garrett advised they were working together on this matter in an attempt to come up with an expeditious resolution to the problem';

- Areas of investigation included APU and APU bay. Modifications being developed included new oil seals, and airframe modifications such as the re-routing of drains, improved intake sealing…;
- *'It is envisaged that the final resolution to the problem may not be in position for some time yet'*;
- *'You may be rest assured that maximum efforts are being made but in the meantime the cooperation of all concerned would be appreciated - If necessary, and when smells become apparent, APU air bleeds should not be used.'*

BAe stated the source of the fumes as follows *'Reports of cabin air odours have been received from time to time and have predominantly been determined to be due to minor systems failures such as leaks from oil seals on the aircraft engines or APU.'* [3] Additionally, BAe viewed there was an '*acceptable standard industry level of oil fumes'* when stating: [3]

- *'There was an oil leak problem in the BAe146 in 1991-92 and that reputation persists today despite the fact that modifications have been in produced to engines and auxiliary power units which have reduced the frequency of oil leaks to an industry standard level.'*
- *'British Aerospace has throughout remained sensitive to the customer needs and concerns, and has in particular worked with the manufacturers of the engines and the APU to produce a package of optional modifications in 1992, and more...'*
- *'Those modifications have been introduced and those modifications have been proven to have dramatically reduced the incidence of leaks on this aircraft to a level which is now consistent with other aircraft worldwide.'*

A 1991/1992 BAe SIL reports that *'the cause of the cabin smells is contamination of the ECS system, especially the ECS packs. The sources of contamination are… 1) oil from an engine shaft seal failure. 2) oil from an APU compressor seal failure. 3) APU inlet ingestion of contamination from the APU* *bay. The reason why the APU is frequently linked to cabin smells has yet to be fully established, however it has been proven that the APU supplies bleed air at higher temperature to the ECS system. The higher temperatures make it more likely that any contaminant in the ECS system will break down chemically and produce smells.'* [244] Eight modifications were listed in the BAe cabin smells trouble shooting SIL. The acknowledgment that oil was the source of the problem continued over the years with statements including: *'there is evidence to suggest that Mobil Jet II is largely responsible for what we are experiencing.'* [245] Progress was noted to be *sadly 'a bit fragmented and in need of "project management skills".'* [245]

Minutes from an Ansett Australia BAe 146 odour inquiry meeting provide evidence that Avro International Aerospace (A.I.R.), a division of British Aerospace regional Aircraft, *'presented an overview of BAe 146 odour investigations around the world.'* [246]

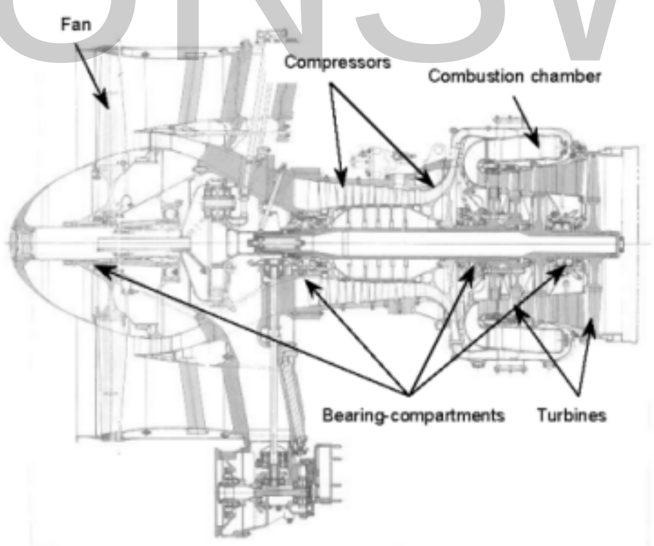
In September 1997, an internal Ansett email was sent to Captain Trevor Jensen, Chief Pilot at Ansett, reporting that Air BC in Canada was experiencing cabin crew complaints on their BAe 146s, including oil fumes and bad odours, cabin crew feeling sick with nausea, sore throat, burning eyes, rapid heart rate and trembling hands and at least one case diagnosed as *'neuro poisoning.'* [247] The email states that *'BAe had told Air BC that no other operators were experiencing cabin crew complaints about cabin air quality, that is until recently, when they admitted that they had 127 other reports (probably from Ansett).'* Ansett also became aware that recent international studies from the National Institute of Occupational Health in Denmark indicated '*TOCP was definitely classifiable as toxic to humans... This generally contradicts results of studies by the oil companies and Allied Signal who consistently conclude that there are no bad effects from TCP in engine oil (until recently the tobacco companies have stated smoking was not addictive and did not cause cancer).'* [247]

With regards to the ALF 502/507 engine fitted to the BAe 146, *'the bleed air for the air-conditioning system takes place via a ring-formed duct in the outer shroud of the combustion case abreast of the engine's combustion chamber. The outlet is placed on the upper portion of the combustion case shroud. Depending upon the thrust setting of the engine, the temperature of the engine* *bleed air varies between 100°C and 400°C. On most modern jet engines, the bleed air outlet is located farther forward on the engine, i.e. somewhere on the compressor section of the gas generator.'* [116]

The ALF 502 engine is reported to be different from most other engines in 2 key respects: [116]

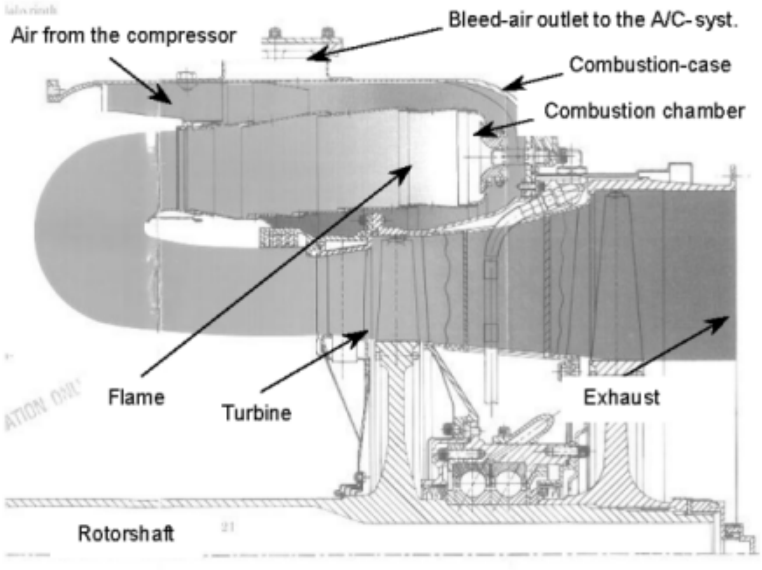
- *'The air extraction takes place unusually far back on the engine. The drawing off takes place directly from the combustion case shroud that is mounted aft of the compressors.'* As depicted in figure 6.1 *'the combustion chamber is situated in the combustion case. Inside the combustion chamber the temperature can reach up to approximately 850°C.'*
- *'The seals for the engine bearing compartments do not all have knife-edge seals that are supposed to take care of the possible oil that normally can leak out in small amounts from oil lubricated carbon-seals after a certain time of operation.'*

Figure 7-2: BAe 146 ALF 502/507 engine schematic



'Both of these circumstances are disadvantageous for the quality of cabin air and could provide an explanation why the BAe 146 series of aircraft, with this type of engine installed is over-represented concerning reports of contaminated cabin air.' [116]

Figure 7-3: BAe 146 ALF 502/507 – Burner section



Burner section

The combustion case and combustion chamber are designed so that air that is bled off for the air conditioning system shall not be able to contain any combustion gases or air that has been in contact with hot surfaces in the combustion case. However, ingestion of oil mist or overheated oil product into the air conditioning system is possible and secondly, the *'bleed-air outlet is located very close to the combustion chamber.'* [116] Additionally as the air is taken from output of the HP compressor only, this is the point at which temperatures in the compressor are at the maximum.

'During the years the aircraft type has been in service, some operators have reported intermittent events when unpleasant smells were found to be coming from the air-conditioning system. The air in the cabin has been experienced as stale or as smelling of oil… Among operators and crews of the aircraft type, it is a known phenomenon that even a slight internal oil leakage in one of the engines can be manifested in a distinct smell of oil in the cabin. When this happens, the cabin air can also assume a somewhat bluish tone.' [116]

7.3.2 Evidence from East West and Ansett Australia

7.3.2.1 General

Ansett commenced operating the BAe 146 200 series aircraft in 1985, while East West Airlines in Australia, which became part of the Ansett group of companies, commenced operating the BAe 146-300 series aircraft in 1990. Ansett took over engineering responsibility for East West in December 1991.

In 1991 East West and Ansett Australia established a BAe 146 Cabin Odour Inquiry Committee. It ran from 1991-1992 and 1996-1998. [248,249] The committee collated *'BAe 146 cabin log odour occurrence reports',* exchanged information between the airlines and unions, participated in various initiatives including monitoring, modifications, medical issues and communicated with other industry bodies.

As an airline operator, Ansett were at the forefront of this problem. They had a significant (up to 17) number of BAe 146-200 and 146-300 aircraft including the original East West BAe 146-300 series aircraft. As such, Ansett/East West were operating both the ALF 502 and 507 engines.

A 1991 internal Ansett Engineering Release (BA6-49-10-5) noted *'flight crew are consistently reporting 'oil fume smells' in cabin.'*

A 1992 Ansett report stated: *'…VH-EWS reported a bad odour prior to landing ...when the APU was selected on. After landing smoke and fumes filled the cabin and cockpit. The technical crew went on to oxygen. The APU compressor oil seal carbon insert and oil filler cap pin were found broken. The exterior of the APU was found contaminated with oil… This oil had been re-ingested into the air supply inlet plenum and combined with oil from the failed oil seal insert allowed smoke and fumes to enter the cabin... With the progressive introduction of modified No. 1 and No. 9 bearing oil seals on the engines, the oil system ejector modification on the APU's oil leakage into the air conditioning system has been drastically reduced. Engineering are currently reviewing cabin airflow, APU to airframe interface, filter reliability, cabin cleaning, and toilet servicing to ensure cabin air quality improves further without deterioration.'* [250] *'Engine Defect report – oil smell in cabin: Probable cause of defect: Cracked front compressor bearing oil seal carbon insert and broken oil filler cap locking pin...*

Recommendations to prevent recurrence: This is an ongoing defect and investigations are continuing... ' [251] The crew member undertook a legal claim subsequent to this action which acknowledged MJO2 injured the lungs. [131]

A 1992 East West Airlines letter to a staff member [252,253] stated *'The issue of odour on the BAe 146-300 series is of course a worldwide problem ...In addition to the considerable resources we have dedicated to this problem, other operators and manufacturers including British Aerospace, Garrett and Lycoming have been working to resolve this issue. This engineering activity has achieved significant results:*

- *Major equipment modifications and operating procedural changes made to the APUs and air conditioning system has dramatically reduced the occurrence and level of odour in the cabin, however has not totally eradicated the problem;*
- *BAe have confirmed the availability of new prototype air filtration units… and are seen as the long-term fix to the problem… The promise of a total fix lies with the new filtration units…'.*

The letter also stated *'it is extremely regrettable that the nature and experience of the cabin odour detracts from our excellent standard of in flight service, particularly in these extremely competitive times... it is essential that the reporting of any odour is conducted through the proper channels and not the subject of discussion outside of East West.'* [252,253] Ansett later advised the Australian Senate Inquiry that during this 1992 period, based on the Ansett/East West fleet of BAe 146 aircraft, fume reports were logged by pilots in the aircraft technical log at a rate of 1 in every 66 flights. [36]

A 1992 Ansett Engine defect report covering several defects noted amongst other causes *'the exterior surfaces of the APU were heavily contaminated'* and *'this is an ongoing problem and BAe, Garrett and Ansett… are conducting extensive investigations to locate the cause of this defect.'* [254] Such defect reports were completed by engineering, each time a fumes event was logged in the aircraft technical log noting the problem and rectification steps taken.

There are many different types of internal Ansett reports listing oil fume defects and fume events. A selection of these include:

- Component Condition History Record – listing 60 entries of the air conditioning packs dirty/contaminated with oil from early 1993 to late 2001; [255]
- Ansett In-flight Health Surveys*, 'odour occurrence reports'* completed by flight attendants and pilots. These were collated between 1991 and 2000 with in excess of 772 available for review. There are many forms and a significant proportion indicate problems; [36,248,256]
- *'Fog in cabin when purging AC – really bad smell.'* This indicates that pack burn outs were carried out when crew were on the aircraft getting ready for flight;
- *'Hot, tight chest, light headed, purser on oxygen. Later nauseous... F/O had to sit in terminal after previous flight to recover.'* This indicates the crew were not fit for flight and unable to meet the airworthiness regulations;
- *'Trembling hands, hot, tingling, sweating, dizzy, laboured breath on descent. No fumes.'* This is an indication how symptoms could occur despite no detectable fumes;
- Passenger reports reported frequent flyers experienced fumes and adverse effects on an ongoing basis and others on selected flights;
- Pilot General Flight reports: One of these marked to the attention of the airline chief medical officer noted contaminated air in flight questioning if tricresyl phosphate in the oil could be hazardous;
- Aircraft technical log reports regarding oil fumes were recorded at a rate of one in 66 flights in 1992; 1 in every 131 flights in 1999 [36,115,257] with 775 oil fume defects reported in 2.5 years;
- Engineering Discrepancy Reports: A review of Ansett discrepancy reports over the period 1992–1994, highlights 3828 reports provided by Ansett in legal proceedings on cabin air. [258] A further analysis indicates 544 incidents were listed as *'oil smells'* or *'smoke/fumes/haze in the cockpit'* or oil smells were reported and an oil leak was found on inspection. A further 122 reports state there were *'APU smells', 'A/C*

smells', '146 smell', 'Acrid smells' or 'Foul smells'. There are another 150 reports which contain technical summaries relating to oil contamination problems such as *'A/C contamination'*, *'Engine leaking oil'*, *'APU cooling fan leaking/sooting'* and such like. Others may be related but did not provide enough detail to confirm oil as the problem. Examples include:

- '*For info: oily smell from APU air whenever used. Noted. APU air not to be used. To be investigated at comp conv. Checked for leaks, nil found. Extensive ground run carried out. Nil smells evident*';
- 'Nil time for further investigation';
- One report claims breathing problems in crew and that the APU cooling shroud seals are broken and letting 'asbestos' into the airstream.

A 1993 Textron Lycoming service letter subsequently advised that engine parts made from asbestos, while no longer currently available, could be still used in engines that had not been overhauled or disassembled. Warnings were applied for the engineers with the purpose of the service letter being to comply with OSHA OHS standards. [259]

In attempting to explain the frequency of oil fumes occurring CASA advised that *'All engines and APUs leak oil and suffer fumes as a feature of the design of air conditioning systems using bleed air.'* [260] BAe advised all engine oil seals leak and it was a function of the design. [3,257,261,262] BAe Service Bulletin 21-46 notes oil fumes tended to occur on initiation of the APU; large changes in engine power with bleed air on (leading to changes in bleed air inlet flow, pressure and or temperature conditions). Therefore a high frequency of reports can be expected. The US FAA also supported the recognition that contamination of the bleed air by engine oil was a *'design problem'* in 2003 when considering issuing an AD to address the problem of oil contamination of the BAe 146. [121,122]

7.3.2.2 Early Ansett engineering awareness and actions

Ansett advised Garrett in 1992 that they saw *'the problem as far from over'* and Ansett had spent considerable sums of money trying to clean up the aircraft. [263] Ansett was concerned both Garrett and BAe were spending *'as much time* *“defending” as “rectifying”’ the problems.’* The BAe 146 East West fleet was said to be an embarrassment to the airline with their customers and an embarrassment to Ansett Engineering. The letter advised Ansett, East West and Ansett New Zealand could not continue this way and questioned how many customers East West would have lost due to the problem. Ansett took the position that given the elapsed time of the ongoing problem any other manufacturer would have solved the problem long ago and it was questioned *‘ how much research has Garrett and BAe really applied to this problem… has the research been academic or have practical exercises been carried out?’*

A 1992 circular from the engineering union to all licensed aircraft maintenance engineers employed at Ansett made a number of important points: [264] *‘The Association is concerned at the potential health and safety risks involved in carrying out pack burnouts on the air conditioning systems on the BAe 146 aircraft.’* The circular also advised that members should utilise on board oxygen *‘during the phases of the pack burn outs when vapour/mist is produced.’* Pack Burns were advised to be no longer used as routine maintenance in 1997 [135,136] and was noted as such in BAe SIL 21-45 issued in 2000.

In 1992 British Aerospace advised the CEO of Allied Signal that the oil problems with the Garrett APU had led to a *‘lack of credibility of the engineering management at Phoenix’* (Garrett) with the *‘situation so critical’* that both Ansett and the trade union had advised BAe that the next occurrence on the BAe 146-300 would lead to the aircraft being *‘grounded.’* [233] BAe advised it required an *‘unequivocal commitment’* from Allied Signal that it could share with its *‘concerned customers that the cabin odour problem will be eliminated in the shortest possible time.’* [233]

BAe advised Ansett in early 1992 that with regard to the ‘APU related cabin smells’, that much of the effort had been put into developing a leak proof carbon seal with Garrett. [265] Garrett and BAe *‘disagree with Ansett’s suggestion that a carbon seal will always leak a small amount.’* Garrett advised carbon seals would provide a long leak free service, however accepted that all carbon seal designs could eventually leak. [265]

Ansett New Zealand engineering actions when fumes were reported included the *‘Glade Test’*. [235] Air freshener was sprayed around the air intake and if found present in the cabin air, BAe SB 49-28-36098B was undertaken amongst other actions and if not the APU may be replaced due to suspected compressor seal leakage.

Avro documentation from 1995, reveals a *'philosophy difference between Textron and Ansett with regard to engine overhaul. Prior to the recent power by the hour deal between Ansett and Textron, Ansett were responsible for their own engine overhauls and the costs thereof. Not unnaturally Ansett interpreted the engine manual as it was written that is, if a seal was serviceable, even though part worn that seal was left in place. Now that Textron are responsible for the costs of engine overhaul they (Textron) have chosen to replace all disturbed seals regardless of degree of prior use. Textrons' field experience suggests that this philosophy will pay dividends in prevention of minor oil leaks and the attendant smells. These technical actions should prevent any more problems with smells entering the cabin.'* [266] Cabin attendant smells were described by the BAe technical representative, as dehydrated (enlarged) sinuses due to habitual flying and increased physical activity in conjunction with cabin odours leading to increased susceptibility to airway irritation. It was therefore suggested that flight attendants take Vicks or Soothers lozenges to relieve the sinus problems. Additionally lower duct temperatures (cooler cabins) were suggested to also *'reduce the propensity of a previously contaminated air conditioning system to smell'* as shown in the 1984 SIL 21/7.

In 1996 Ansett suggested changes to its operating procedures in an effort to reduce the oil fumes. [267] Before landing four minutes was to be allowed between activation of the APU and use of the APU air. This was increased from two minutes so as to allow *'oil seals within the APU to seal, and any oil within the plenum to be dispersed within sufficient time prior to air loading the APU.'* Additionally the current practice of selecting and leaving the cabin air in fresh after take off for the duration of the flight was to be replaced by leaving the air in RECIRC. This would reduce *'the bleed from the engines thus conceivably, also reducing any contamination from the engine oil system into the air conditioning system.'* [267]

7.3.2.3 BAe Hatfield meeting, August 1992

While the oil fume events on the Ansett BAe 146 were ongoing and not rare, a particular event occurred on a BAe 146-300, VH- EWJ on 5 August 1992 with the failure of a *'new bellows seal'* on the APU. [268] A letter from the Chief General Manager of Ansett to the President of British Aerospace Regional Aircraft, advising this event had *'placed the ongoing program to manage the cabin odors in serious jeopardy'* with the real possibility that a further occurrence of significant contamination would see flight attendant refusal to crew the aircraft with a *'significant impact on the Ansett Group.'* [268] The problem was seen however as one involving oil leaks in the engine and APU and the Ansett General Manager requested what actions and time frame involved BAe would take to resolve the *'cabin air contamination situation.'*

Consequently in August 1992, Ansett learned from BAe that they were having a meeting with Garrett in the UK. Alan Harrison, Ansett Aircraft Maintenance and Overhaul Director attended this meeting. [269] Ansett considered there was still another 4-5 months *'to live with the smell problem on the 146'* and it really needed to do something to *'remove some of the heat from the flight attendant fraternity.'* John Playford, Industrial Officer of the FAAA was also invited to attend as an observer to allow *'BAe to suitably impress the representative with the work being done by BAe on the problem.'* [269]

The meeting held between BAe, Garrett, Ansett and the FAAA took place in August 1992, for which no minutes are available. However, Ansett documentation provides an insight to what occurred at the meeting: [270,271,272]

- *'It would be an understatement to say that there is considerable friction between both parties (Garrett/BAe) over the subject of cabin smell';*
- *'The seal leaked as a result of coked oil particles getting between the seal and the rotor interface… Garrett still claims that the build of the APU fitted to EWJ is a contributing factor to the failure of the seas';* [273]
- *'It would appear that the seal which we believed was designed for the job is in fact an existing seal used within a military application';*

- *'However you wish to look at it, Garret claim the seal height was excessive and thus seal face pressures were above design limits... BAe do not support this position';*
- *'After almost 3 hours of bickering between BAe and Garrett with Ansett principally looking on…'*;
- *'The last few days have been extremely hectic, and sometimes very emotional, between BAe and Garrett. For the most part our role as the customer of BAe has been one of sitting on the sidelines and watching'*;
- The flight attendant representative advised BAe and Garrett *'that another situation similar to the EWJ experience would positively see the flight attendants refuse to crew the aircraft.'*
- *'I believe the situation is so delicate that we should consider operating the 300 fleet with the APUs not used. I believe they will live with the engine leaks (with pack burnouts) but the APUs could see the 300 out of action if another event occurs which sees the cabin heavily contaminated.'*

A BAe document sent to Ansett engineering clearly stated BAe unlike Ansett believed the problem of cabin air contamination lay with APU and that 'prejudice has been allowed to override rational judgement.' [274] BAe believed there had been and continued to be *'a determination to prove that the main engines are the cause of the problem, at least to a large extent… Allowing the APU to continue contaminating the systems while trying to identify the "guilty" engine and replacing it is expensive and futile.'* The correspondence was written in *'some anger'* as *'the reputations of the company and product… have suffered probably irreparable damage because of an unwillingness to accept that the problem lies somewhere other than where it is wanted to be. Had BAe been listened to from the beginning we would now be a year closer to having a solution. As it is BAe at their own ill afforded expense are introducing a costly filtering system to mask the rubbish coming from another vendor's product. There are people within your own company who have given Garrett the assurance that the problem was not theirs, or theirs alone, so please do not direct all your frustration at BAe and Garrett.'* [274]

The meeting outcome was that the wrong APU seal had been specified and Ansett engineering was likely contributing to the problem. Additionally, Ansett clearly realized the problem extended beyond the APU. [268,270] Outcomes of the meeting were: [271]

- *Garrett to provide a new factory built APU with correct seal bellows installed FOC (free of charge);*
- *Garrett to provide FOC a mechanic from the APU build areas to work with Ansett Engineering to turn around all the 150M APUs, complete with Seal Bellows, to the Garrett tolerance. 'The mechanic will stay as long as it takes and will have his fingerprints in every build';*
- *'In a nutshell Garrett will have ownership of the work performed on every APU installed within the -300 fleet. If a failure occurs they will have no-one to flick pass the problem';*
- *'Until the APUs are returned to service based on the Garrett specification, it is essential we operate the APU with the Bleed Air off (MEL)';*
- *'The proposed filtration system looks good and six ship sets (Masefield) will be delivered by the end of October';*
- *'I have struck a general understanding with John Playford (union) on the subject of cabin smells... the members will be asked to accept odours from engines in the short-term, however if an APU suffers a major loss of oil... the association will be told not to crew the aircraft and thus ground the aircraft.'*

Ansett advised BAe that in addition to the soon to be trouble free APU *'what we must collectively do now is apply pressure to Avco Lycoming such that they also develop engine oil seals to keep the bleed air system free of oil contamination.'* [275]

The main outcomes of the August 1992 meeting at Hatfield in the UK were that correct seal system would be installed on APUs and a cabin air filtration system would be installed on the BAe 146-300 aircraft.

A 1992 Flight Attendant's Association of Australia (FAAA) BAe 146 memo on the fumes advised that *'British Aerospace is confident that the new filter system will work under all circumstances... Garrett in conjunction with Ansett will continue to work on the seal problem…'* [276]

However, the filtration system installation was problematic and quickly fell behind schedule, [277] as can be seen in the various engineering releases and service bulletins in Appendix 2. A 1993 Ansett engineering release for example which followed BAe Service Bulletin SB 21-70-01316A, indicated the process to be followed for the BAe 146-300 airplanes: catalytic converters were to be removed; ECS ducts were to be replaced; coalescers were to be installed; cockpit and cabin filters were to be installed; and the pack valve to duct seal was to be replaced. [278] In a review of how successful engine modifications had been in October 1993, Mr Brian Girdwood, Engineering Fleet Manager, noted that *'installation of the new filtration system had been successful and has had a significant effect on reducing the number of reports of this problem.'* [279]

BAe had previously met with a French company, Le Bozec in 1992, regarding their filtrations system. [280] The cabin smells problems were said to have spanned the previous 18 months, source of the odours was said to be the ECS packs although the investigation of the 'bleed air smells should look at the whole bleed air system right back to the engines and APU. BAe suggested that the modifications had gone some way to eliminating cabin smells, however a *'fool proof system of preventing cabin smells'* was now required as there would never be an engine or APU carbon seal that does not eventually wear out and fail. Additionally, BAe advised that the solution must be finalised by the end of July 1992 *'bearing in mind BAe's responsibility to Ansett'* and asked when would *'BAe design be satisfied that the equipment is effective. BAe cannot afford a protracted in house test.'* [280]

In 2004 Ametek Aircontrol Technologies advised that they provided activated carbon filter elements for the BAe 146 and 146/RJ flight deck and cabin, using activated carbon cloth (AAC) manufactured by Vapour Management Systems. [281] The AAC, originally developed in conjunction with CDE Porton Down was stated, to be manufactured to the same specifications to those supplied to the military NBC applications and said to be *'good at adsorption of nerve gases* *which are organophosphorus compounds.'* [282] Amatek advised the life of the filter would depend partly on the exposure contaminants and how the aircraft was operated. [281] As will be seen below, the Ansett filters were problematic and Allied Signal advised Ansett in 1997 that hydrocarbons were breaking through the filters with higher molecular weight molecules occupying the available filter surface area necessary for trapping other compounds, thus preventing the filter from effectively removing odours for the calculated filter life expectancy. [135,136] Additionally physical damage was observed on the cabin filters either occurring from excessive heat melting the thermostat adhesive, or excessive bleed air temperatures exceeding the 100^{o}C temperature limits. While it is not known what filtration system the BAe 146 was using in 2005, a 2005 proposal provided by Donaldson to BAe Systems noted the greater efficiency of the Donaldson filtration media over a *'competitor's filter media.'* [283]

However in late 1994 BAe/Avro (AIR) whilst advising the *'problem of cabin odour is caused by the air conditioning system being contaminated by oil'*, Avro advised Ansett that with regard to the ongoing problems associated with the life of the filters no further financial support (filter elements) would be provided. [284] Avro advised that the 150 APU carbon seal was the primary problem (and an ejector modification to the APU had reduced the possibility of oil contamination) along with modifications to engine seals 1, 2 and 9 (the seals had been modified and an air diffuser had been re-designed). [284,285] The manufacturer believed the modifications undertaken would be *'effective in eliminating cabin odours'*, however it anticipated that airline industry would require higher standards of cabin air quality. As such the filtration system would be fitted as standard on all 146/RJ aircraft and it advised Ansett to consider retaining the filtration system *'to guard against general airborne impurities.'* Avro advised only three months later that it was *'disappointed to learn'* that Ansett was in the middle of a *'cabin smell campaign on a 146-200 series aircraft.'* [285] While the APU and engine modifications were considered by Avro to have resolved the problem, it was advised contaminated packs and ducting could be a source of cabin smells if not cleaned after rectification of oil leaks.

A September 1992 document from British Aerospace Australia to Ansett discussed planned corrective actions to be taken to eliminate oil smells attributed to the engines. [286] Textron provided information to BAe in relation to service bulletins it had issued in 1984 *'following sporadic customer reports of cabin odours. Modifications were undertaken through SB ALF 502 72-0076 (4/84) through revision 6/86.'* Compliance for this service bulletin (reissued in 2000) was published as *'recommended at convenient access.'* Textron had acknowledged that in recent years potential *'oil leak paths to the bleed air have been continually reinforced with new assembly procedures and inspection requirements, repair procedures and component improvements which Textron will continue to release to the field engines in the form of engine manual revision and service bulletins.'* [286]

Modifications were not installed across the entire BAe 146 fleet, however and installation progress was slow. [287] A 1995 circular from Ansett to Cairns and Perth based crews notes *'JJJ is at present in the hanger having major work on the engines and will be back on line with new filtration units.'* [288] This was nearly three years after the initial circular, and two and a half years after when the filtration units were available.

A 1996 Ansett engineering document to Avro support noted the problematic history of the filters and coalescers with the cabin and cockpit coalescer filter containers often *'heavily contaminated with APU/engine oil.'* Ansett noted the BAe service bulletin SB-36-28-36136B and Avro testing found that *'coalescers were not effective at extracting APU/Engine oil in aerosol form from the airconditioning system.'* [289] The report continues to state *'as it is not uncommon for the engines and APU to suffer from oil seal leakage, it is quite amazing that AVRO have not taken a serious look at fitting an air/oil separator in the bleed air system ducting to prevent this type of occurrence.'* The cabin and cockpit filters were found to be *'limited in life and not adequate to do the complete job'* and as such the air/oil separator idea was suggested to extend the filter life and reduce costs. Additionally, the report shows that Ansett questioned the high monetary cost of addressing the problem in addition to the affect on staff and customers flying the BAe 146 aircraft when stating: [289]

- *‘This incident adds to the already high cost of managing the cabin smell issue for Ansett. Not only the monetary cost of parts and labour, but the effect on staff and customers flying the BAe 146 aircraft. Please don’t leave it all to the operator to resolve, let’s stop the oil contamination near the source.’*

Ansett advised BAe in 1996 that, based on the 1994 BAe SIL 21/34, filters would last on an aircraft between 180 and 240 flight hours with aircraft operating between 7-10 flight hours per day per aircraft. The costs were therefore assessed at Aus$ 630,000 annually and Ansett consequently asked *’what is AVRO doing to improve the performance of the filter elements and reduce cost to the operator.’* [290]

Avro International Aerospace advised Ansett in 1996 that it intended to send swabs taken from the airconditioning ducting back to England for analysis looking for any unusual components, particularly *‘plant pollen and insect originated sources.’* [291] However Ansett Engineering release, BA6-21-20-20-17 indicates the *‘ducts become dirty and smelly due to oil and dirt accumulation.’* The Avro representative advised that in his opinion the ducts were dirty and could be contributing to the smells and was *‘dismayed’* to learn that an engineering release based upon SIL 21/21 relating to the air conditioning pack health monitoring and cleaning [292] had not been enacted on any of the Ansett fleet. Avro restated its position that when cabin smells were reported, Ansett should find and rectify the source of the smell, followed by a *‘rigorous program of cleaning, ducts and ECS packs should be followed prior to releasing the aeroplane for service.’* Pack burnouts were to be used for troubleshooting and to provide temporary relief from the symptoms with the duct cleaning covering all the ducts before the filters and such ducts after the filters found to be contaminated by examination. Avro agreed that instead of removing the ducts for cleaning, a pull through idea could be used.

By 1996, problems were still occurring largely by way of continuing complaints by *(‘mainly’)* flight attendants about the BAe 146 cabin smells. Ansett’s General Manager Technical, wrote to Avro (A.I.R.), noting *‘However, we must find ways to keep Mobil II out of the packs or we fear it is only a matter of time before every 146 in Australia is against the fence.’* Ansett advised that *‘Unless we can* *find a meaningful solution I will have no other choice but to suggest to Ansett that we phase out the type.'* [293]

7.3.2.4 The confidential agreements

Soon after the 1992 Hatfield meetings, three 1993 agreements were made between Ansett and East West on one part, and BAe, Avco Lycoming (engine manufacturer) and Allied Signal (APU manufacturer which had taken over Garrett) on the other (see Figures 7.2, 7.3 and 7.4). These agreements follow a similar pattern with a qualifying preamble, the terms of the agreement and signatures. Ansett was aware of the economic losses caused by the oil problem evidenced in numerous correspondence including an internal July 1993 Ansett memo indicating that revenue losses due to maintenance and delayed flights were to be included in the Ansett *' submission to BAe on recoveries.'* [294] Likewise, Ansett New Zealand prepared a detailed cost breakdown for it's costs incurred due to leaking oil from the engines or APU into the cabin, which were to be presented *'to BAe as part of the combined Ansett Group claim.'* [295]

In a 1999 letter to Ansett from the Chairman of the Australian Senate Inquiry into Cabin Air Quality in the BAe 146, the question was put: *'I would be grateful if you could inform me about any legal action undertaken by Ansett Australia with British Aerospace as a respondent, the disclosable outcomes of such outcomes, and the current status of such outcomes.'* [296] Captain Trevor Jensen, Executive General Manager Operations and Inflight Services at Ansett advised in his reply that *'Ansett Australia did not in 1992 or at any other time initiate any legal proceedings against the aircraft manufacturer British Aerospace, in respect of the BAe 146 aircraft'.* [297]

The agreements, were disclosed by Senator Kerry O'Brien of the Australian Senate in August and September 2007 when tabled in the Australian Senate. [298] This was 14 years after Ansett, British Aerospace and the other entities (now part of Honeywell) had drawn up the agreements and six years after Ansett had gone into administration.

Figure 7-4 Ansett East West – BAe Agreement: 3 September 1993.

First Agreement

<u>Ansett East West – BAe agreement: 3 September 1993</u>

Preamble: Pursuant to the Aircraft Purchase Agreements, BAe warranted that relevant parts of the Aircraft (as therein defined) would conform to applicable specifications supplied by BAe and would be free from defects due to defective material or defective workmanship or defective design on the part of BAe all in accordance with and subject to the terms, conditions and limitations contained in the Aircraft Purchase Agreements.

Ansett and EWA have made certain written claims against BAe alleging defective design of the Aircraft resulting in the production of obnoxious oil and other (the *'cabin environment problem'*) fumes affecting the passenger cabins of some or all of the Aircraft.

Following certain discussions and negotiations the parties hereto have agreed to settle such claims upon and subject to the terms and conditions hereinafter contained.

Agreement: BAe hereby agrees with Ansett and with EWA that it shall pay to EWA the sum of Australian $750,000 (Seven Hundred and Fifty Thousand Australian Dollars) which sum shall be paid as follows:

- Aud $300,000... being an interim payment in respect of such claims, on or before 31st August 1993.
- The balance of Aud $450,000... ...on or before 31st January 1994.

Payments …made on an "ex gratia" basis …is not in any circumstances to be construed as any admission of liability ... Ansett and EWA hereby jointly and severally agree that the said sum of Aud $750,000 shall be paid by BAe to EWA as liquidated damages in full and final settlement of any and all claims which Ansett or EWA may have against BAe either now or in the future in respect of oil or other fumes adversely affecting the cabin environment…

Ansett and EWA have advised BAe of their intention to seek further compensation from the respective manufacturers of the APUs and engines installed in the Aircraft... It is hereby agreed that BAe shall... provide to Ansett and to EWA such technical data as may - reasonably be required.

Terms: The existence and terms of this agreement are confidential between the parties hereto and shall not be disclosed by any party in whole or in part to any other person or body without prior written consent of the other parties.

Figure 7-5 Ansett East West – Avco Corp. (Textron Lycoming) Agreement: 1993.

Second Agreement

<u>Ansett East West – Avco (Textron Lycoming) agreement: 1993</u>

Preamble: Whereas, Ansett and EWA are the operators of certain BAe 146 Aircraft powered by ALF502 gas turbine engines manufactured by Textron Lycoming (the "Engines"); and Ansett and EWA have alleged that they experienced engine bleed air problems between the date of purchase of the aircraft in 1989 and early 1993 (the "incidents") and that their experience with the Engines has shown that various deficiencies and inadequacies exist in the Engines, and that such deficiencies and inadequacies have resulted in economic loss to Ansett and EWA, (the "Loss"); and Textron Lycoming has denied that there exist any such deficiencies or inadequacies in the Engines, or that Ansett and EWA or either of them have suffered economic loss due thereto; and Textron Lycoming and Ansett and EWA desire to settle and terminate immediately all disputes, differences and claims between them in relation to the Loss and to avoid future controversy and expense with respect to the foregoing:

Agreement: Textron Lycoming agrees to pay to EWA the cash sum of US $150,000.00 within thirty days of the Signing... and credit of US$100,000, to be used relating to the purchase of new spare parts and/or new parts.

Terms: Except as specifically agreed to otherwise in writing in advance by Textron Lycoming and Ansett and EWA both of them agree to maintain the existence and all terms of this Settlement Agreement in strictest confidence and to disclose any terms hereof or information relating hereto only its employees and legal or other professional advisors. Disclosure to such advisors however may be made if they agree to be bound to the confidentiality requirement set forth on a “need-to-know” basis.

Figure 7-6: Ansett East West – Allied Signal Agreement: 1993.

Third Agreement

Ansett East West – Allied Signal agreement: 1993

Preamble: EWA and Ansett are the operators of certain BAe146 Aircraft incorporating Allied Signal Auxiliary Power Units ("APUs").

Soon after delivery of the aircraft, it became apparent that the bleed air system in the aircraft periodically circulated an unpleasant smell throughout the cabin.

After detailed and protracted investigations, it was determined that a source of the smell was oil leakage from Allied Signal APUs which entered the bleed air system through the air conditioning packs.

Over the course of several years of investigation and combating the cabin smells, significant costs were incurred by EWA and Ansett (the "Loss").

Allied Signal has denied that there exist any deficiencies or inadequacies in the APUs or that it has in any way contributed towards the Loss.

Allied Signal and EWA and Ansett seek to settle and terminate immediately all disputes, differences and claims between them in relation to the Loss and to avoid future controversy and expense with respect to the foregoing.

Agreement: Allied Signal will provide to EWA and Ansett a total Parts and Labour Credit of one million two hundred and thirty-five thousand dollars (U.S.) (US$1,235,000) as financial consideration associated with the operation of Allied Signal APUs on BAe146 aircraft... available to EWA and Ansett in three individual credit releases...

Terms: EWA and Ansett and Allied Signals agree to maintain the existence and all terms of this Settlement Agreement in strict confidence and not to disclose any terms hereof or information relating hereto save as to the extent required by law.

In 2007 Lord Tyler commented in the UK House of Lords: *'What is the Government's reaction to the fact that BAE seems to be more concerned about the leak of this document than about the leak of toxic fumes into aircraft cabins and cockpits with potentially disastrous consequences?'* [299] The Government responded that the agreements amounted to matters *'between commercial parties'* and matters for the parties concerned only and two of the parties (East West and Ansett) no longer existed anyway. [299,300]

On the other hand, the Australian Senate stated that the Australian parliament was *'effectively lied to by Australian operators, particularly Ansett'.* [301] Senator O'Brien criticised the airlines, particularly Ansett regarding the agreements and compensation relating to bleed air as they had advised the Senate 'there was no problem yet, on the other hand, they were signatories to an agreement to be compensated for the problem.' Senator O'Brien when questioning the ATSB in Senate Estimates hearings commented that *'it was likely fair to say that ATSB would have received the same sort of evidence from Ansett that the Senate committee received—that is, that the problem was not able to be determined by their own inspections and they were not aware of* a significant bleed air problem.' [301] The ATSB replied *'I think that is a fair statement.'* While such an act was deemed *'contempt of the Senate',* the ATSB advised that under current legislation the consequences of misleading the ATSB involve *up to 6 months imprisonment,* however, at the time former regulations were in place involving *up to 150 penalty units.*

The US FAA, when asked about the implications of the documents (given they involved the major Aerospace company Honeywell), also advised that the '*US FAA does not get involved in contractual agreements between manufacturer's, operators or other companies… such agreements are outside the scope of our regulatory authority ...therefore it is inappropriate for me to comment further on these documents.'* [302] The former Australian Prime Minister's response failed to answer the question of his view on the secret documents. [303]

The BAe view was that *'BAE Systems reached a commercial agreement with the airlines which involved no admission of liability on BAe Systems' part in respect of alleged poor CAQ on aircraft supplied to them. The commercial agreement reflected the inconvenience and costs incurred by the airlines as a result of investigating those allegations and demonstrating that the aircraft met satisfactory air quality standards'*. [304]

7.3.2.5 Air quality monitoring program

Ansett undertook various air monitoring studies over the years from 1992 as can be seen in Chapter 5, however most proved to be of little use, apart from the Fox Allied Signal studies in 1997, which found TCP, however the information was left out of the official reports [135,136] It was known that TCP had been found in the George Lee studies in 1997 [305] and by Fox of Allied Signal based on the Ansett odour inquiry meeting minutes. [306] However, it was not until 2007 that documents were released, showing that Allied Signal had detected TCP *'during and after pack burns.'* [307,308] Despite this conclusive knowledge, Dr Lewis, the Ansett Chief medical officer (CMO) advised *'the chemical that everybody is worried about and is surmising is the cause of the problem has never been recorded in an aircraft. This is TCP, tricresyl phosphate.'* [115] Subsequent questioning regarding the finding of TCP in Ansett aircraft by the Senate Inquiry, showed that Dr Lewis stated it was an *'immeasurable blip.'* [115] Additionally, the company official position stated three years later that TCP had never been found in any aircraft or Ansett testing. [309]

The Ansett Odour Inquiry minutes that raised the TCP findings in the Allied Signal/Ansett sampling advise that Don Love of A.I.R., Avro, stated that the full Allied Signal/Fox report would be available in two weeks and that *'filter analyses were proceeding in the USA. Trace quantities of TCP were found in the filters but none in the cabin air. Tar looking substances were also found.'* [306] Subsequent minutes show that *'Don Love replied on behalf of A.I.R. and reassured the committee that no cover up or pressure had been brought to bear… A.I.R. had not affected Air BC from coming to this meeting. The Richard Fox report is not available due to internal policies within Allied Signal. Don reassured that everything was above board'* and he was presenting as much information as he could. [310]

The minutes also reflect that *'Don Love and Bruce Rogers of A.I.R. presented their report addressing the history of the problem, the issue development, the cabin smells committee, technical trouble shooting, information support and the cabin air sampling program.'* [310] Ansett minutes from the year before show that A.I.R indicated that the report data from the company chemist at Air BC, was *'not consistent with previous data.'* [246] This will likely be the results from the 1996 Air BC monitoring undertaken by UBC. [311] In 1998 an internal Ansett email in response to awareness that the 1996/98 van Netten UBC studies noted that crew reported extensive adverse effects over a four-month period. The memo from Dr Lewis of Ansett states: [312]

- *'This confirms that BAe and Allied Signal have been lying thro their teeth. Can't we do them?'*

A testament to additional problems with the monitoring can be seen in a memo from Ansett's CMO Dr Lewis. He advised that he had received the results of various air sampling studies and scientific tests would cost $1000 per flight sector, however a less specific test sampling for oil mists only, was available which *'would not in itself prove of any great use in a court action.'* [313] The simple test referred to by Dr Lewis could be conducted in house by Kevin Currie of the engineering department and would cost about $55 per sample. [313] This was in fact what happened as shown in Chapter 4 and nothing of concern was found. The flight attendant union and Allied Signal both noted the high failure rate of such sampling and the fact that such techniques were not suitable for capturing the heavier weight SVOCs (typical of oil products) respectively. [135,136,248]

Another example of Ansett air monitoring involves the 1993 BAe 146 air filtration tests undertaken with Ansett personnel as well as the BAe customer support representative for Ansett and the Textron-Lycoming customer field service rep. [314] The report noted that *'numerous reports of cabin air contamination by smoke and smells from engine oil …resulted in a major redesign by BAe to the aircraft airconditioning system. During the testing 'the presence of an "irritating" smell and oil mist within the cabin …was* <u>*confirmed*</u> *by all members of the test team who were present. This being a subjective test, the reports of discomfort varied among individuals',* with one member reporting *'severe irritation'.*

With regard to the Allied Signal testing, the Ansett odour inquiry minutes stated *'Don Love of AIR* [Aero International Regional] *stated a full report from Richard Fox would be available in two weeks*. *Filter analyses were proceeding in the USA. Trace quantities of TCP were found in the filters but none in the cabin air. Tar looking substances were also found.'* [306] These data was deleted from the final reports, by Allied Signal Aerospace.

As another example, while Ansett had claimed all it's monitoring including the 1992 WorkCover monitoring had shown the air was clean, [315] a WorkCover NSW representative in 1998 advised *'A number of years ago we carried out sampling for oil mist in this model aircraft but found only a low levels of contamination. The testing was not carried out in flight and the comment was made at the time that the contamination is spasmodic so the results of our testing may not necessarily be representative of actual situations'.* [316]

A December 1997 communication between Ansett's Trevor Jensen and the CMO, Dr Lewis, showed that given the Allied Signal monitoring studies were to be presented to Ansett that morning, Dr Lewis was aware based on the regulations that the BAe 146 did not meet certification standards. Dr Lewis advised that the BAe 146 failed to meet the ventilation airworthiness regulations, specifically the ventilation, noxious vapours and contamination requirements. [308,317] Despite this, Ansett continued to insist its aircraft monitoring program showed all its aircraft met all the rules. [115] Further review of Chapter 5 will provide further detail on Ansett studies.

7.3.2.6 Later Ansett engineering awareness and actions

Over the years, Ansett undertook a range of modifications on the BAe 146. The airline advised it spent in excess of $7 million [115] on modifications, and initiatives to the BAe 146 (labour, materials and engineering development costs). *'We have taken an aircraft already certified by the airworthiness authorities and we have spent millions of dollars on improving it.'* [115]

Ansett Australia and the Ansett pilot union advised the Australian Senate Inquiry in 2000 of an extensive list of modifications including: [115,287,318,319]

- BAe 146 air conditioning system modification program;
- BAe 146 power plant modification program;
- BAe 146 APU modification program.

British Aerospace also advised the Senate Inquiry that it had undertaken extensive modifications; however those provided to the Australian Senate Inquiry were only a fraction of those later sourced by the author. [1,3,320]

British Aerospace advised the Australian Senate Inquiry that the *'suite of optional modifications in 1992'* had been very well received while others claimed certain modifications had essentially fixed the problem. [3] In 2009 BAe referred to the new number 1 oil seal introduced from 2003 (previously modified in 1995) and stated *'with the new oil seals fitted there have been no failures to date (10 million flying hours).'* [304]

In contrast BAe also advised that: [1,3]

- *'The modifications will not solve the problem completely. They are to reduce the number of events, and that is what is important'*;
- *'The modifications that have been developed are really around the reliability of the seals and making sure that they do not fail as frequently.'*

In a 1998 legal case, a leading Ansett Engineer stated that *'The filtration was never to rectify the problem; it was to provide some relief to the problem.'* [249] The limitations of the filter technology utilised by Ansett were clearly summarised by a leading filter manufacturer. Carbon adsorbent filters for VOC/odour removal using activated carbon are suitable for low temperature applications (up to 70°C), however the filter efficiency decreases as contaminants accumulate on the adsorbent, so the elements require removal and replacement at regular intervals. [321]

An senior Ansett pilot and pilot union representative advised in 1997 that the 'BAe 146 aircraft has an inherent problem with Mobil Jet 2 engine and APU oil fumes entering the aircraft air conditioning system. These problems can be traced back to the British Aerospace Service Information Leaflet 21/7 Dec 94: Oil Contamination of the Air Conditioning System. Until very recently very little effort seems to have been expended in seeking a suitable and permanent fix for this problem. [322] The memo reveals that Allied Signal provided an engine modification kit and a guarantee that this would eliminate future oil fume events, along with concern that there was no such commitment from the APU manufacturer Garrett Air Research (part of Allied Signal). While Ansett efforts were noted to be partially successful, the problem was said to still remain. The aircraft manufacturer, AVRO, A.I.R., *'be-grudgingly noted there is a problem of contamination and their efforts seem to have been directed more to the short-*

term quick fix solution, rather than investigating or acknowledging that perhaps there is an inherent design fault in the system which may necessitate a total replacement or re-design of the air conditioning system. This is clearly evidenced from the fact that since service bulletin (SIL) *21/7 DEC84 contamination of the air conditioning system has remained a persistent problem on all models of the BAe 146 aircraft.'* [322]

7.3.2.7 Awareness of health effects

Ansett was aware of the 1983 Mobil letter stating that '*if the cabin air becomes contaminated with any lubricant and/or its decomposition products, in sufficient quantities, some degree of discomfort could occur'.* [79]

However, in a 1993 inter-office memo between the CMO at Ansett, Dr Lewis and Kevin Sullivan (Ansett Air Freight), Dr Lewis noted *'This is a worldwide problem with BAe 146 aircraft'* and *'The contaminant is known to be pyrolytic products of Mobil Jet Oil II having leaked into the air conditioning packs.'* [323] It was also noted that while *'fumes can be an irritant to mucous membranes there is no hazard to health from long-term inhalation exposures… the problem remains an engineering one and filters, catalytic converters …are being trialled.'* [323]

In 1997, an internal Ansett email to Trevor Jensen discusses Ansett's continuing research on the effects of TOCP and notes that recent international studies (National Institute of Occupational Health, Denmark) indicated *TOCP was definitely classifiable as toxic to humans... This generally contradicts results of studies by the oil companies and Allied Signal who consistently conclude that there are no bad effects from TCP in engine oil (until recently the tobacco companies have stated smoking was not addictive and did not cause cancer).'* [247]

An Ansett pilot union representative advised that although to date there was no definitive health risk established, *'enough evidence exists to show that ingestion of the oil fumes can be the cause of, or lead to, various illnesses. That risk will remain as long as there is contamination of the air conditioning system.'* [322]

In 1998, Ansett published a consensus statement accepting that *'Short–term symptoms associated with odours that have been reported on the BAe 146 and* *other types are substantiated.'* [112] These were described as *'irritation of the upper airway mucous membranes, headaches, nausea, lethargy, minor shortness of breath and light-headedness',* amongst others. [115,319,324,325]

7.3.2.8 Occupational Health and Safety

The occupational health and safety initiatives that took place must be reviewed in terms of the admission by Ansett that *'The source of the odours has been identified as predominantly Mobil Jet Oil II leaking past engine oil seals into the air conditioning system'.* [115,319]

In at least May 1992, Ansett's health and safety department received a 1991 Mobil Australia customer circular that advised *'there is no risk to health with normal use of Mobil aviation products containing tricresyl phosphate because the amount of TOCP is less than 0.1%.'* [326] The memo incorrectly refers to the hazards of the *'3'* [sic] TCP isomers with TOCP being the most toxic, suggesting that TOCP in the oil would therefore be less than 0.03% and notes TCP is classified as hazardous under OSHA regulations, but not so in Australia. A similar document was sent to Ansett in 1997 stating the TOCP is in the oil at *'probably'* less than 0.02%. [327] 1998 internal Mobil correspondence (sent to Ansett) explains why the MSDS for MJO II was upgraded to include inhalation warnings and that based on 3% TCP, Mobil studies had shown the oil was safe and TOCP was restricted to less than 1% in TCP. [103] The changes were made based on product safety practices and Mobil argued it was unaware of the problems faced by Ansett until *'recently'.* Mobil of course was aware that the other ortho isomers of TCP were in the oil at higher quantities than TOCP and were far more toxic and that this had been known since 1958. [96,99,100,104] In 1997, Ansett raised an internal Mobil customer request regarding Mobil Jet Oil II. [328] The request advised that *'Ansett believe that a confidential air safety report has been submitted by an Ansett pilot to the Bureau of Air Safety Investigations suggesting cabin fumes in the BAe 146 aircraft may have caused pilot problems during a flight descent. Ansett believe there is a potential for the aircraft to be grounded... '*

In April 1995, Queensland Workers compensation began denying WorkCover claims by Ansett flight attendants. [313] It was confirmed that Queensland

WorkCover did not require any more sampling as previous investigations had covered their concerns and they would now be denying WorkCover claims. [313] Likewise the Health and Safety Organisation in Victoria advised Ansett it no longer thought monitoring was required, however a number of other actions were suggested. [329] In August 1995, the Ansett occupational risk manager, Kevin Currie asked the A.I.R. Australian rep (Bruce Rogers) if he had ever received a response from BAe regarding his 1991 question regarding the health effects of exposure to oil fumes. [241] No response is available for review, however a response was provided by Allied Signal to BAe. [242] The response given by Allied Signal to BAe was essentially that while the oils exposed to high temperatures can break down, there were no health hazards apart from long-term continuous immersion of skin in the oil or where long-term ingestion occurs. [242]

Numerous letters were held by Ansett relating to crew being sent for medical assessment or passengers complaining of ill effects. These included four East West crew sent to an occupational physician in 1992 for assessment who advised symptoms were consistent with poor air quality and operation of the APU. [330] A 1995 report from a passenger advised of regular adverse effects after flying on the BAe 146. [331] In 1995, a Dr Shaughan Terry wrote to Ansett's Medical Director responding to a reply about a flight attendant he was treating, suggesting: [332]

- *'Most of the investigation that you have sent me were done by British Aerospace themselves and I wonder whether these investigations are useful from a scientific point of view as they must inevitably be biased'* and *'there is a consistent complaint from crew in many different airlines and from different countries that there is a problem with this particular aircraft'*.

Dr Lewis then sent a facsimile to Queensland workers compensation consultant Advisor, Dr Pat Carroll regarding the response from Dr Shaughan Terry stating that with regard to the *'latest on the 146 saga'* Dr Carroll's name appeared in the correspondence and *'what think ye of Shaughan Terry's letter? (a celt?)'* [333]

From October 1995, in a letter to the Ansett Flight Attendant National Manager, Dr Lewis, based on Dr Carroll's Queensland Work Cover statement, concluded that there was 'no *toxicological hazard in the BAe 146'* and Dr Carroll who was assigned to see all applicable Ansett flight attendants (in Queensland) was to speak to a treating specialist, *'hoping to put him right.'* [334] Dr Lewis then stated that he would *'continue to try and reverse certifying Drs opinions.'* He then advised that: *'with this complicated situation there will need to be a senior management operational decision to allow or deny these requests in that a roll on effect can be expected and it may look as though we accept liability.'* [334] Dr Lewis began attempting to advise the medical practitioners contacting him with a view to suggesting that the problem was somehow not related to oil leaks on the BAe 146 and he advised medical tests should be limited. [335,336] Additionally Dr Carroll who had stated there was no toxicological hazard, suggested any formal review would likely not be successful for the airline, despite the *'overwhelming'* scientific evidence. [334]

In 1995 internal Ansett correspondence regarding workers compensation costs, Dr Lewis stated *'This problem has already cost several million engineering dollars and is now emerging as a likely very costly workers comp and litigation problem not to mention heightened union concerns. Everyone is hoping this will not go outside the company.'* [337] It was also noted that the problem had been going on for some years. The Ansett Corporate Manager of Flight Attendants suggested that if Ansett monitored the problem, it could *'control the process'* and that while QBE (insurer) was *'directed to pursue the authenticity of these claims',* it was understood this was in hand. [338]

In an internal document, titled *'BAe Pong'*, Dr Lewis expressed concern about a flight attendant having been recommended not to fly on the BAe 146 by her personal physician, (Dr Shaughan Terry) based on the pending sampling data. [339] Dr Lewis also suggested the exemption should not be accepted as *'we all know its Mobil oil and non hazardous. As all the aircraft use it, a ban on the 146 makes no sense.'* While trying to contact Dr Terry without success, Dr Lewis reported that *'this may blow up so I'll leave notes in your in tray if I've failed.'* [339]

In March 1996, Dr Lewis in an inter-office memo to Alan Harrison, General Manager –Technical Dr Lewis noted: [340]

- *'We are unlikely to ever fix the engineering problem to the Flight Attendants satisfaction';*
- *'They are repeatedly and inadequately briefing external agencies who then make their recommendations on ultra-poor data';*
- *There are plenty of new age doctors out there prepared to make non-evidential medical diagnoses such as 'Multiple Chemical Allergies';*
- *'The Flight Attendant Association continue to run us ragged.'*

In this confidential internal memo, [340] Dr Lewis suggested the direction to be taken was to form a committee of experts, present the data, *'accept their recommendations and run firm with the expected non hazardous result. This will cost some dollars, but probably less than pack burnouts and short-lived filters.'* He also suggested Ansett contact it's OHS lawyers to seek advice on bringing *'the new age physicians to account – industrially and commercially, not medically… bring in the expertise of Mobil as it is their oil anyway.'* [340] Ansett subsequently did set up an expert panel and provided the experts with carefully selected limited data, all cited by the author.

In 1996 an Ansett internal confidential memo advises that Mobil was to *'provide details of their "smell test" protocols.'* [341]

A standard Ansett letter to medical practitioners attending Ansett crew after odour exposure was formulated, which noted that the odour is *'most commonly due to contamination of the air conditioning system with small amount of volatile organics produced from vaporisation of engine lubricating oil.'* [325] All VOC testing had shown substances to be in *'very low concentrations, far below occupational exposure limits.'* A variety of short-term transient *'common symptoms of exposure'* were listed including *'rhinitis, pharyngitis, conjunctivitis, headache, nausea, lethargy, light-headedness, occasionally shortness of breath, confusion and co-ordination difficulties'*, with symptoms noted to be rarely supported by confirmatory signs. No long-term health effects were caused by exposure according to the Ansett letter to doctors. The letter advised that there were no useful diagnostic or clinical tests that could be used as an *‘extensive database has yielded no associated abnormalities.’* Dr Lewis asked for all clinical findings to be sent to him personally on a confidential basis.

Notes taken by a Medical Practitioner (who had seen numerous crew) during a 1996 meeting requested by Dr Lewis after an adverse Sunday media report on the BAe 146 show that the Ansett CMO stated *‘I thought we had this under control until the story broke in the Sun Herald’* and that *‘he had been given the job of sorting this mess out before it gets out of hand.’* [342] Dr Lewis then suggested the Doctor did not understand the commercial implications of this issue *‘which could threaten Ansett’s very existence.’*

From around 1992, after proceedings in the Industrial Relation Commission, flight attendants were exempted from flying on the BAe 146 if they had supporting medical evidence. [248] However, from around early 1996, aircrew that had medical certificates to be excluded from flying on the BAe 146 were rostered back onto the aircraft. Concern remained with the flight attendants and by November 1996, the FAAA sought advice from Ansett about the issue where industrial action was again discussed. [343]

In April 1997, Dr Lewis advised the Ansett General Manager Operations that based on activities undertaken to date as well as those proposed, he felt the airline would have *‘great difficulties satisfying the concerns of some flight attendants’* who may *‘adversely affect our operations into the future – ad infinitum*’ and if this was the case Ansett should plan an *‘active defence and hold it in reserve’.* [344] Dr Lewis’s draft letter stated that despite MJO II being non toxic, flight attendants who experienced *‘adverse reactions’* or *‘supersensitivity’* to the smell of MJO II, enough to cause days lost would be transferred to ground duties (under it’s due diligence policy) where they have to work longer hours or overtime to retain similar incomes. [344] Additionally Dr Lewis noted that *‘a threat of loss of flying duties worked well before East West were absorbed.’* A week later Dr Lewis advised a crew member’s physician that *‘We would attempt to find ground duties for your patient should you regard the degree of her reaction justifies such a recommendation*.’ [345] Dr Lewis advised that as the oil used was *‘the industry spec. worldwide and present as a smell on all our other aircraft types’,* it would not be possible to expose such a supersensitive person to duties in any of the Ansett aircraft. [345]

While pack burn outs following seal failures were supposed to be conducted while the aircraft was empty, it was a common practice for such burnouts to be carried first thing in the morning, while crew were getting the aircraft ready for its first flight. In April 1997, as a measure to counter industrial action, *'gas masks'* were placed on the flight deck for pilots to use during pack burn procedures. [346] That same month Ansett Engineering revised the instructions for air conditioning pack burn outs, including stricter attention to the absence of staff on the aircraft. This can be seen as a change from the BAe 1984 SIL procedure recommending pack burnouts before the first flight of the day should oil contamination occur. In November 1997 (after receiving the Allied Signal Fox report), an Ansett BAe 146 Update noted that *'the procedure of a daily pack burn will cease from Wednesday 24 December 1997'.*

In 1997, Ansett was advised by a pilot union (AAPA) representative that *'The captain as pilot in-command, has an implied legal and moral obligation to the well being of all crew members and passengers whilst on-board an aircraft under his control. It is of concern to the AAPA and to many captains that they may not be able to meet this obligation whilst the problem of oil contamination continues from the APU.'* [322]

Despite awareness of health effects associated with inhalation of oil fumes, when questioned about pilots experiencing vertigo related to fumes, Ansett's CMO, Dr Lewis produced a medical advisory circular assuring pilots that concerns were not justified. [347] Vertigo, causing light headedness, dizziness and a feeling of being off-balance was according to the circular caused by a variety of conditions, of which none were caused by toxicological agents and that no toxic substances had been detected in the monitoring (AGAL) undertaken. Such negative results were said to have been *'confirmed by British Aerospace on their 146 aircraft worldwide.'* [347]

In March 1998, an *'Expert Panel of Specialists for the BAe 146 Odour Occurrences'* convened by Ansett, meet in Brisbane and agreed that *'The source of the odours has been identified as primarily Mobil Jet Oil II leaking past oil seals in the engines and or APU unit into the air conditioning system'* and *'The short-term symptoms associated with odours that have been reported on the BAe 146 and other types are substantiated. These odours have been* *generally linked with inadequate ventilation together with aircraft system defects.'* [36,112]

While Ansett had previously acknowledged that oil leaks were occurring on the BAe 146, this was the first public admission that exposures could cause adverse effects, even if only short-term effects were acknowledged. A March 1998 circular acknowledged the short-term effects as *'irritation of the upper airway mucous membranes, headaches, nausea, lethargy, minor shortness of breath and light headedness',* amongst others, also identified officially by Ansett to medical practitioners. [319, 324,325]

A 2000 Ansett *'confidential and subject to legal privilege document'* supplementary submission document relates to substances in the cabin air, the airline's research findings and flight attendant duty exemption. [309] The document advised amongst other issues that the following company position points were to include:

- TCP; TOCP has never been detected in Ansett testing;
- Dangerous substances were not present in the BAe 146 cabin air;
- 115 samples showed all samples were harmless and below Government set levels (1998 AGAL/VOC sampling);
- Chemicals *'may only enhance odiferous or irritant effects';*
- BAe 146 is fit to be crewed by all flight attendants.

These briefing points were made despite Ansett knowing very well this information was inaccurate. The AGAL studies using Tedlar bags were known by Ansett not to be effective and unable cannot to monitor for SVOCs. [136,313] Despite claiming that all levels of contaminants were 100th to 1000th of the Government exposure standard limits, [115,309] the technique was severely criticized with *'The failure rate of the kits was so high that with hundreds of attempted samplings, only 57 successful samples could be analysed.'* [248] Additionally, Dr Lewis and Ansett were well aware that TCP had been identified in the 1997 aircraft testing. [305,306,307,308] Additionally, Ansett (Dr Lewis and Mr. T. Jensen) were well aware that the BAe 146 failed to meet airworthiness ventilation standards. [9, 308,317]

A May 2000 *'BAe 146 return to work program - Flight Attendants information kit'* was provided by Ansett for crews to give to their doctors as medical exemptions were no longer going to be accepted. Ansett advised the crew and their doctor's that they had carried out exhaustive studies, monitoring, modifications and concluded there was no toxicological hazard or long-term health risk. [319] A graduated program would be used to assist crew return to work on the BAe 146. As of May 2000, approximately 140 cabin crew were exempted from working on the BAe 146. [115]

The Ansett position should be reviewed in a broader industry context. CASA had clearly stated at the 1999/2000 Senate Inquiry that the issue of aircraft air quality was outside its expertise and that it was an aviation regulator that was responsible for short and medium term effects that had a direct implication on air safety. [260] At the same inquiry, BAe stated: *'The regulatory bodies as admitted by CASA yesterday, are not competent to rule on such a highly specialised area. Neither are the airlines or the manufacturers'.* [3]

7.3.3 Later BAe 146 general actions

Other BAe 146 operators, while not anywhere near as open as Ansett, were also experiencing contaminated air problems. Some limited examples are set out below:

National Jet Systems (NJS), which had operated the BAe 146 since 1991, commenced investigation of the oil fume problem in 1997 after a BAe 146 freighter incident into Melbourne. The incident resulted in incapacitation of the Captain and Ansett subsequently then agreed to share its air sampling research results with NJS. [37,348] In 1998, NJS engineering initiatives included *'The engineering department has been actively involved in initiating several maintenance actions which will significantly reduce the instance of oil odours and also enhance the ability to locate the source and perform a timely rectification…'* Actions included the replacement of all engine main bearings, carbon seals and seal seats at 5,000 hours (reduced from 10,000 hours; removal and cleaning of air conditioning packs at 'C' check intervals - every 2000 cycles (reduced from 6,000 cycles), operate in fresh mode wherever possible and a trial of third generation oil, Mobil 254 (which PSA had trialled in

1985). [349] NJS did not view that all suspected fume events that came to the captain's attention (including verbal reports from cabin crew) ought necessarily to be reported by the captain in the aircraft technical log as a defect, despite the regulation requiring such actions. NJS also suggested cabin crew should send all fume event reports direct to the airline and not copied to unions. [350,351]

In 1998, NJS advised staff that *'Oil fumes are detected in minute quantities… and short-term effects, while medically not harmful can cause irritation of the nose, throat, eyes and can cause headaches'.* [352] In marked contrast, NJS acknowledged in 2003 that it was unable to provide a safe working environment to an NJS pilot, as it could not totally eliminate oil fumes and accepted *'it could not guarantee a pilot would not be exposed to fumes, the likelihood is that the pilot would be exposed to fumes and that therefore there is a risk of damage to his health.'* [120]

In 1999, BAe advised that given that *'dangerous chemicals exist in the oil and that we have sick people at the other end of the chain'*, new oils *'reputed not to have some of these toxic elements in them'* were trialled. The upgraded MJO II warning labels in 1998 were described by BAe as *'horrifying'* and consequently trials of MJO 291 were undertaken *'to try to find a better oil which does not contain those constituents.'* MJO 291 according to BAe was said to maybe *'not be better in terms of smell, but at least it does not have the dangerous warning label on it from the manufacturer.'* MJO 291, which in fact contained lower levels of the ortho TCP isomers, [96] was subsequently withdrawn from use. [353,354]

In 2000 British European (later became FlyBe), a major BAe 146 operator advised that it was undertaking a range of actions in a confidential Internal memo to all BAe 146 pilots given that: [355]

- *'in common with many other BAe 146 operators, we are experiencing an increase in cabin air quality incidents... We believe the issues that we are experiencing are due to oil smells or fumes getting into the cabin/cockpit environment via the air conditioning packs. This of course is not the source of the oil; the source is either the engines or APU. Solving the oil source problem is a lengthy process and involves engine manufacturers etc., which will take time to resolve. The immediate task however is to stop the smell/fumes getting into the cabin conditioning.'*

In 2001 British Aerospace commissioned an analysis of the (unidentified) jet engine oils by DERA, Pyestock (QinetiQ). [356] The oil was subsequently determined to be Exxon 2380. [357] The research is marked, *'Property of BAe Systems… Restricted-Commercial'* and the report is, *'Subject to legal privilege and therefore exempt from disclosure.'* [124,358,359] The UK CAA was allowed limited access to this research only and as of mid 2009 had not been made available to any other parties. [358] Despite the confidential nature of this report, the report became the basis of the 2004 UK CAA cabin air report that suggested oil substances were an irritant only. [124] The UK CAA stating *'BAe Systems confirmed that the pyrolysis study undertaken for the UK CAA was an adequate study.'* [360] The complete report was released under a 2009 freedom of Information request and is referred to in Chapter 5.

Other confidential BAe test data that has not been made available for review includes excerpts from an in house news letter which states [361] '*Filter analysis: Honeywell now have filters from THY and DAT ...testing will be done in-house, although pieces of filter have been offered to Exxon Mobil for their own testing… Honeywell seal test rig: Honeywell are now checking whether the No 1 seal stator distortion observed on the rig also occurs on the engine…'*

The 2001 ALF 502/507 (engine) Operator Conference minutes show some of the industry thinking regarding the oil fumes. [362] The forthcoming UK CAA first AD related to oil fumes was discussed along with the need to *'take action immediately whenever odor evident... with incident having to be recorded and addressed.'* It was deemed therefore that a *'culture change'* was *'required'.* A variety of comments state that: *'Air Wisconsin concerned that this action may cause major increase in number of engine removals, Aer Lingus concerned that they'll end up grounding the fleet due to crew upon the AD being released… Mesaba expressed concern the crews will be writing up everything unnecessarily with no significant problem reported at Meseba. Comment from audience: Condition to inspect engines will ground aircraft. MEL is allowed, but pilot may refuse the continued use of aircraft. Inspectors may ground aircraft.'* The problem was determined *'not to be an organic phosphate'* one nor related to specific oils or fuels, rather CO appeared to be the problem, but CO detectors had found nothing.

In 2005, a UK BAe 146 airline operator issued a *'Notice to Aircrew 15/05'*, highlighting that BAe Systems had *'released advice concerning correct medical actions to be taken following exposure to cabin or flight deck fumes'*. The medical tests recommended were the same as those recommended by BAe in 2000 as part of its SIL 21-45: *'Cabin Air Quality troubleshooting advice and relevant modifications.'* [208]

In July 2005, CitiExpress in the UK stated in an Air Safety Report involving oil contamination that *'smells and irritants from burning organic compounds from within the engines are known to produce harmful volatile organic contaminants'.* [126]

In 2006, FlyBe advised it had voluntarily instigated an investigation into CAQ using sophisticated sampling and analysis techniques and that *'Tedlar bags are used… The samples are analysed at BRE… One VOC was detected but at very low levels… (This VOC is common in aircraft cleaning agents)… No organophosphates could be detected'*. [363] This is the same type of testing that Ansett and Allied signal undertook in the mid 1990s and was noted to be inappropriate to detect oil mists and SVOCs, based on the use of Tedlar bags used in the Ansett AGAL studies and the Ansett/Allied Signal studies. [135,136,248,313] FlyBe management, however, stated the *'industry evidence is clear. The BAe 146 cabin conditioning issue in FlyBe in 2005 is being exaggerated - there was no basis in fact. There was however a great deal of scare-mongering going on.'* [364]

In the same year 2006, FlyBe issued an operational notice to aircrew advising in the event of an air quality/fume event, captains were to ensure that any passenger *'complaining of actual symptoms'* was *'invited'* to attend the nearest hospital to undergo tests, all crewmembers were also *'invited'* to do the same. The defect was required to be reported with an ASR raised. [365]

In summary, there have been many contaminated air incidents on the BAe 146/RJ, as evidenced in this thesis. Some have been more high profile than others, such as the 1997 Australian NJF event, the 1999 Swedish Malmo event, the 2000 FlyBe Birmingham incident and the more recent Swiss event in 2006. However, BAe (and virtually all others) advised in 2000 that the Swedish incident air quality testing (refer Chapter 5) [116] had found nothing that could explain the incident. [366] The Swiss incident, however, was far clearer with the final Aircraft Accident Investigation Bureau investigation report stating: [367]

- *'The serious incident is attributable to... the cockpit filled with fumes which caused a toxic effect… caused by an oil leak… The medical examination of the co-pilot... showed that during the flight toxic exposure took place.'*

Despite suggesting there was no evidence of what was causing the problems, BAe in 2000 stated: [3]

- *'There is absolutely no doubt in our minds that there is a general health issue here. The number of people who have symptoms indicates that there is a general issue ...Our assertion is that it is a health and safety issue, it is not a safety issue... With the weight of human evidence and suffering, which is quite clear, there must be something there.'*

7.3.4 Australian Senate Inquiry 1999-2000

In 1999, the Australian Senate announced it was going to hold an inquiry into a number of air safety issues. One of the issues was cabin air quality on the BAe 146. A large number of submissions were received (31 public and 22 private) for the BAe 146 Inquiry that was separated out from the others due to the level of public interest. The Senate Rural and Regional Affairs and Transport References Committee, chaired by Senator John Woodley conducted the year long inquiry. [36]

Nine public hearings were held where oral evidence was heard in Canberra, Sydney and Brisbane from November 1999 to August 2000. The Committee also heard number of private submissions. Although there were differences of opinion on some issues, all parties within the inquiry committee agreed that: [36]

- Oil can leak into the aircraft passenger cabin due to the use of bleed air;
- The problem is not unique to the BAe 146;
- Contaminated air has led to certain short and medium term (10 years) health effects;

- Contaminated air conflicts with regulatory requirements;
- Strong evidence of under-reporting;
- Modifications improve the problem but do not eliminate the incidence of fume exposures;
- Potential of occupational illness and inability to fly;
- Exposure to chemicals can have long-term effects.

The Committee's report, published in October 2000, contained eight recommendations covering accident reports, air conditioning system modifications, development of a suitable fume monitoring test, review of the toxicity of the oil, health monitoring of crew and passengers, review of workers compensation cases and cabin air filtration. [36] The Australian Federal Government's response to the Report of the Inquiry was for the Civil Aviation Safety Authority (CASA) to establish an internal Cabin Air Quality Reference Group to monitor developments in this area, which met twice in 2002-03, but thereafter did very little. [368] None of the report's eight recommendations were ever actioned, apart from the CASA raised airworthiness directives.

7.3.5 Official BAe 146 industry documentation - BAe 146/146 RJ

7.3.5.1 General documentation

A sample of the BAe 146 official documentation from 1984 to 2003 involving service bulletins, service information leaflets, all operator messages, selected airline official documentation, through to airworthiness directives is shown in Appendix 2. [1,320] Several more recent documents have been added to this list since this time to demonstrate the ongoing nature of the problem; however an updated list of documentation was not actively sought. While most of the information comes from the various manufacturers, some comes from two Australian BAe 146 operators as well as selected International and Australian regulatory authorities. Once again, this will only be an example of the type of data that will have been available, as the data are difficult to source and not generally easily available for public review.

Table 7.2 is an updated summary of the data shown in Appendix 2 of official documentation and as such is a case study of some of the data available documenting the contaminated air issue on the BAe 146 and the BAe 146 RJ. [1,320] The table includes revisions, mainly up until 2003, with only several further documents added. There are in fact over 220 sources of data showing that contaminated air was a serious and well-known issue. Such data were previously made available for review by aviation regulators is no longer publicly available for inspection according to advice provided by the UK regulator to the author based on *'liability issue*s'. [369]

A number of examples of manufacturer, airline and regulator documentation available are listed below in Table 7-2. These have been selected from Appendix 2. The information has been gathered from a variety of sources and does not differentiate between the BAe 146 and its successor, the BAe 146/RJ aircraft.

Incomplete information in some cases is due to the fact that the information is not generally available for public review and comes from a variety of sometimes difficult to obtain sources.

- **British Aerospace: Service Information Leaflet (SIL) - 31 August 1984**

  SIL 49-1 BAe 146: 'APU - Taping of APU plenum chamber.'

  'It is possible for APU bay fumes to be ingested by the APU and enter the aircraft cabin through the air conditioning system…'

- **Allied Signal, Garrett APU Division: Service Bulletin (SB) - 13 December 1984**

  SB GTCP36-49-5562: APU - Incorporate improved compressor seal assembly.

  Reason: Examination of APUs returned from service indicates that oil leakage can occur in the area of the compressor housing attachment bolts and past the compressor seal internal packing.

Table 7-2 Summary of official BAe 146 data shown in Appendix 2

Report Type	Source	Year (s)	Number	Source Examples See Appendix 2
Service Bulletins - Aircraft Manufacturer	BAe	1984 to 2009	86+	BAe SB 49-5, 49-36, 21-150 and 21-156
Service Bulletins - Engine	Textron Lycoming/ Allied Signal/ Honeywell	1984 to 2003 +	29+	Allied Signal SB ALF502R 72-342
Service Bulletins - APU	Allied Signal/ Garrett APU Division, Allied Signal (AS)	1984 to 2001	15+	Allied Signal SB GTCP36 49-5899
Service Information Leaflet	BAe	1984 to 2008	21	BAe SIL 21-7, 21-45 36-9, 21-27, 36-11, 21-30
Service Information Leaflet	Allied Signal/ Honeywell/Textron Lycoming	1973 to 2001	6	Allied Signal SIL ALF/LF-8
All Operator Message	BAe	1999 to 2003+	7	BAe AOM 00/030V
Internal engineering releases/orders	Ansett (BAe/AS)	1992 to 1998	33	BA6 21-20-29
Various: EMM, CMM, MM, Engineering notice, Internal memo	BAe, Honeywell, Normalair/Garrett, NJS, Ansett	Various	12+	NJS Notice to BAe 146 pilots 37/97
Airworthiness Directive	CASA, CAA, FAA - BAe 146	1986 to 2003	10	CAA AD 002-03-2001, CASA AD/BAe 146/86
	TOTAL for period: 1984 - 2003		**220 +**	

- **British Aerospace: Service Bulletin (SB) - 24th October 1984**

  BAe 146 Aircraft Modification SB 49-5: Airborne Auxiliary Power - Power Plant - To Introduce an Improved Compressor Inlet Duct Seal (Garrett Change 13).

  Reason: Inadequate sealing between APU accessory drive gearbox oil sump and compressor inlet duct, and between top and bottom halves of inlet duct, allows fumes to be sucked from the bay area through the APU and into passenger cabin.

  Description: Improved silicone rubber seal configuration. This SB is for information only. Retrospective embodiment is not intended because in service experience has shown that this modification is not a complete answer to the problem.

  Compliance: Information

- **British Aerospace: Service Information Leaflet (SIL) – 1 December 1984**

  SIL 21-7 BAe 146: Oil Contamination of Air Conditioning System.

  The following advice is offered should oil contamination of the air conditioning system be experienced:

  1. Use of 1 air conditioning pack on ground… will reduce the extent of contamination in the event of APU oil leakage;

  2. If the system becomes contaminated by oil, unpleasant cabin odour may be alleviated by: a) Operate system before 1st revenue flight of the day in hot mode (70 deg C) for 5 minutes… This will help to purge residual oil from the packs and ducting b) avoid high duct temperatures in flight...;

  3. In the event of severe pack contamination, the equipment should be removed... and cleaned in accordance with… Normalair-Garrett maintenance manual 1780...;

4. It is recommended that the air conditioning system be operated in recirculation mode whenever possible as this can reduce contamination of the cabin by oil;

5. Where underfloor cabin distribution ducting has been contaminated by oil, odours in the cabin can persist and it is necessary to clean the ducting… The BWT flexible sound attenuation ducts cannot be cleaned satisfactorily and should be changed if contaminated.

- **Allied Signal, Garrett APU Division: Service Bulletin (SB) - 11 December 1989**

  SB GTCP36-49-5899: APU - Replace compressor seal assembly.

  Reason: Problem: The current compressor seal has shown an unacceptable rate of failure, which can result in smoke in the cabin.

  Background: The failure of the compressor seal assembly allows gearbox oil to leak into the compressor inlet, resulting in smoke in the cabin. The new seal has been redesigned to improve sealing characteristics and reliability.

- **British Aerospace: Service Information Leaflet (SIL) - 12 September 1991, Revision 2, 21 December, 1992 and Revision 3, 12 August 1994**

  SIL 21-30 BAe 146: Air Conditioning - Cabin and flight deck mal odours - troubleshooting - Contamination of the air conditioning system can lead to mal odours in the passenger cabin and flight deck areas. The possible sources of contamination of the air conditioning system are: oil contamination of the bleed air supply… oil contamination of the APU bleed air supply.

  Refer BAe SIL 21-45 (Nov 2000 and subsequent revisions) and SIL 21-46 (2008): Cabin air quality trouble shooting advice and relevant modifications and SIL 21/27 (1990).

- **BAe 146 Internal Engineering Release – Ansett/BAe BA6 49-80-1: November 1992**

  Extra washers at APU exhaust to prevent exhaust gas leakage into APU bay and reingestion causing smell inside cabin. (See: BAe SB 49-30). Work undertaken between July 1993 and February 1998.

- **British Aerospace: Service Bulletin (SB) - 12 January 1993 - Revised May 1993**

  BAe 146 SB 21-70: Air Conditioning - To introduce improvements to the Bleed Air and Air Conditioning Systems to eliminate cabin odours.

  Reason: Service experience has highlighted the requirement for improved quality conditioned cabin and flight deck air.

  Description: Introduces a number of modifications, which combine to form complete filtration system for conditioned air to cabin and flight deck areas. Partial embodiment acceptable.

  Compliance: Information.

- **British Aerospace: Service Bulletin (SB) - 6 July 1993 - revised 26 October 1994 (rev 2), 30 April 2003 (rev 4) and 27 July 2004 (rev 5)**

  BAe 146 SB 49-36: 'Auxiliary Power Unit – Introduction of improved APU inlet flexible duct part # DXA07175.'

  Reason: Existing APU inlet rubber flexible duct is susceptible to damage by oil contamination.

  Compliance: Optional (Rev 4 (2003) and 5 (2004) Mandatory by UK CAA).

- **British Aerospace: Service Bulletin (SB) - 15 December 1993 - revised 1995**

  BAe 146 SB 21-72: 'Air Conditioning - To introduce improvements to the Bleed Air and Air Conditioning Systems to improve Conditioned Air Quality.'

  Reason: Service experience has highlighted advantages in improving the quality of cabin and flight deck air.

Compliance: Optional.

- **Allied Signal: Service Bulletin - April 1995**

  SB ALF 502R 72-342: Engine - Introduction of improved No. 1 bearing seal.

  Reason: To introduce an improved carbon seal assembly… the new secondary seal is made of a more stable material which will help maintain equal force on all areas of the seal contact surface and reduce carbon element wear.

  Compliance: Recommended at operators convenience.

- **Allied Signal: Service Bulletin - June 1996**

  SB ALF/LF 72-1019: Engine – Inspection of air diffuser assemblies with suspect welds on oil tubes.

  Reason: Oil tube assembly kit... cause oil leakage, which results in odour in cabin.

  Compliance: Recommended at 1st access to affected part, not to exceed 7500 cycles…

- **British Aerospace: BAe 146 and 146/RJ Manufacturers Operations Manual - Notice to Aircrew: (2.00.07) Operational Notice: NO.OP.16 and 43 (Issue 1) – Smoke and fumes - January 2001**

  The air supply is protected from contamination by seals, which achieve maximum efficiency during steady state operation. However, they may be less efficient during transients (engine acceleration or deceleration) or whilst the engine is still achieving an optimum operating temperature. Improvements in seal design continue to increase efficiency, and when available, modifications are provided for the engines and APU.

- **British Aerospace: BAe 146 All Operator Message - February 2001**

  BAe 146 AOM: Ref: 01/0004V: Revision of BAe146 and AVRO RJ MOM Vol. 3 - Abnormal and Emergency Checklist - Smoke and Fumes.

  The amendment will consist of the addition of the word FUMES to all titles for the relevant smoke drills...

- **Textron Lycoming: Service Letter - 93R-1, 20 March 1993**

  ATA Code 72: Reveals that engine parts in the field may still contain parts made with asbestos.

- **British Aerospace: Inspection Service Bulletin (ISB) - 21 March 2001 - All BAe146 100, 200, 300 Series**

  BAe 146 SB 21-150: Air Conditioning - Inspect engine oil seals, APU and ECS jet pump and air conditioning pack for signs of oil contamination.

  Reason: Incidents have been reported involving impaired performance of the flight crew. There is some circumstantial evidence that the events could have been caused by inhalation of an agent(s) resulting from oil and/or oil breakdown products leaking from the engine(s) or APU and contaminating the environmental control system. In the past oil leaks and cabin flight deck smells and fumes may have come to be regarded as a nuisance rather than a potential flight safety issue.

  However, whilst investigations are being carried out to determine the nature of any agents that may be released into the cabin environment and to define any necessary corrective actions, oil leaks and cabin flight deck smells must be regarded as a potential threat to flight safety not just a nuisance.

  Compliance: **MANDATORY** by the UK CAA.

- **British Aerospace: Inspection Service Bulletin (ISB) - 31 October 2002 - All BAe146 100, 200, 300 Series**

  BAe 146 SB 21-156: Air conditioning - To inspect air conditioning sound attenuating ducts for signs of oil contamination.

  Reason: Incidents have been reported involving impaired performance of the flight crew... In the past, oil leaks and cabin/flight deck odours and fumes may have come to regarded as a nuisance rather than a potential flight safety issue... This ISB is intended to supplement the ISB 21-150… It has been shown by recent inspection of in service aircraft that sound attenuating material within these ducts has acted as an absorbent for oil contamination on some aircraft.

Compliance: **MANDATORY** by the UK CAA.

- **Allied Signal: Service Bulletin - August 2003**

  SB ALF/LF 72-1082: Field evaluation for the incorporation of a new No 1 seal part… and No 1 seal faceplate part…

  Reason: Current No. 1 seal and faceplate assembly may develop leaks allowing engine oil to enter the high pressure compressor air stream during engine operation…

By reviewing the attached official BAe 146 documentation database, it can be seen there is an extensive and ongoing history of contaminated air awareness and actions stretching from 1984 to recent years. While updated documentation has not been sought, the British Aerospace draft SB 21-157 issued in 2009, involving the introduction of a flight deck air treatment unit to improve flight deck air quality and meet proposed levels in future air quality standards, indicates the ongoing nature of the issue. [370]

Upon close review, it can be seen that many of the same modifications relate to the same area and were ongoing over many years. Just a few examples involve:

- The 2003 oil seal No. 1 service bulletin (SB ALF/LF 72-1082) can be traced back to a 1995 service bulletin (SB ALF502R 72-309). [371] In fact internal Ansett documentation suggest Textron Lycoming were *'developing an improved No. 1 seal'* in at least 1992; [372] The Textron SB was produced over 2 years after the BAe 1992 SIL 21-30 (revision 2) advised *'Textron are shortly to issue a Service Bulletin that will introduce improved sealing for the engine bearing No. 1 assembly*.' [244] Therefore the awareness for the need of an improved number 1 bearing seals dated back at least 11 years.

- A 1984 service bulletin (SB ALF 502 72-0076) related to the *'Introduction of improved No. 2 bearing assembly'* with continuing modifications in 1987 (SB ALF/LF 72-0179); 1995 (SB ALF/LF 72-1009); 1997 (SB ALF/LF 72-1034) and SB ALF 72-1037;

- The 1993 service bulletin (SB 21-70- 01316A) introduced modifications *'which combine to form complete filtration system for conditioned air to cabin and flight deck areas. Partial embodiment acceptable.'* The 2009 Draft SB (SB 21-157) applicable to both the BAe 146 and 146/RJ, was issued to *'improve flight deck air quality'* with the introduction of a flight deck air treatment unit with compliance listed as optional. [370] The Draft SB recommended for in-service evaluation states *'This modification introduces a new air treatment unit which replaces the existing air filter assembly for the Flight Deck air conditioning system.'* This relates to the Quest International Air Manager air treatment system. [373] ;
- The 1992 service bulletin (SB GTCP36-49-6661) was issued as compressor seal leaks were allowing oil and smoke to enter the aircraft cabin. Revision 5 was issued in September 1993. The service bulletin contains the comment; *'Allied Signal recommends that this SB be done at the operators convenience.'* The Ansett Airlines modification program under engineering release AR5-49-20-33 indicates that the work was undertaken between November 1994 and October 1996;
- The 1992 *'information'* Service Bulletin (SB 49-30 led Ansett to issue an engineering release (BA6 49-80-1) which was issued in the same year. The work was undertaken between July 1993 and February 1998. The work was completed over 6 years after BAe first highlighted the specific problem related to SB 49-30 of fumes in the cabin.

Additional service bulletins have been published since 2003 including BAe SB 21-157. Another example is Honeywell SB ALF/LF A 72-1075 revision 2, issued in 2006. [353] Amongst other details, various items could become *'blocked with deposits attributed to ExxonMobil 291 engine oil use.'* ExxonMobil 291 engine oil was noted to no longer be approved for use and was removed from the approved oil listing. The original SB was in fact issued in 2002 and was not cited by the author or included in Table 7.2. Compliance was listed as addressing a *'safety issue.'* BAe SIL 21-146 (replaces SIL 21-45, version 4, November 2006) notes that Mobil 291 was removed from use *'due to incompatibility with certain components in the engine oil system and engine oil* *coking'* as noted in the 2002 BAe AOM 0*2/02.* [354] None of these were included in Table 7.2.

Service bulletins are not mandatory unless the aviation regulator issues an airworthiness directive. Therefore the review of the list of selected service bulletins shows that despite clear awareness that oil fumes were occurring, the SBs were not made mandatory apart from the few ADs listed below and in Appendix 2 from 2001 onwards that were related to the BAe 146 only and not the 146/RJ. Compliance was listed in varying formats that included *'For information, optional, recommended – repair at company convenience/at 1st access to affected part, not to exceed 7500 cycles'* and similar.

7.3.5.2 Airworthiness Directives

In 2001, the lead certifying authority for the BAe 146, the UK CAA issued the first of three Airworthiness Directives for the BAe 146 aircraft. Based on BAe (inspection) Service Bulletin 21-150, the UK CAA issued airworthiness directive AD 002-03-2001. [374] The AD applied to the BAe 146 series aircraft only and not the RJ version and referred to inspection of the engine oil seals, APU and ECS for signs of oil, with maintenance to be undertaken as required. A 2001 UK CAA letter (5 days prior to AD publication) to BAe Systems responds to the BAe and Honeywell justification on why the BAe SB 21-150 was not applied to the 146/146 RJ aircraft/engines. [375] The UK CAA accepted the reasons given by BAe and Honeywell stating that *'the higher mod standard and increased No. 1 and 9 seal buffer pressures in the LF 507-IF engines fitted to the AVRO 146 RJ are plausible reasons for making these aircraft less likely to suffer from the problems currently being investigated. On that basis, the UK CAA agrees that SB 21-150 does not need to be applicable to the AVRO 146-RJ model aircraft.'* [375] However, it was not recognized that the LF 507-IH (rather than the ALF 502 fitted to the BAe 146) was fitted on some BAe 146- 300 series aircraft similar to the LF 507-IH or IF versions fitted to the 146/RJ. [227,376]

CASA issued a similar AD for the BAe 146 series aircraft only (not for the 146/RJ) very soon after followed by the German regulator. [377,378] The UK and German ADs require inspections immediately when cabin air contamination related to oil is identified, whereas the Australian AD requires actioning within the next ten hours if the suspected source is identified and isolated, or immediately if this cannot be accomplished. The US FAA never adopted this AD.

In 2002, the UK CAA issue AD 003-10-2002 based on BAe Inspection Service Bulletin 21-156, requiring inspection of the aircraft ducting for oil contamination. [379] Once again, this AD was applicable to the BAe 146 series aircraft only and was issued as a supplement to the previous AD 21-150. CASA in fact issued a similar AD a few weeks earlier than the UK CAA, while the German AD was revised to include this service bulletin. [380,378] The US FAA mandated SB 21-156 almost 18 months later in mid 2004 stating: [123]

- *'This action is necessary to prevent impairment of the operational skills and abilities of the flight crew caused by the inhalation of agents released from oil or oil breakdown products, which could result in reduced controllability of the airplane. This action is intended to address the identified unsafe condition.'*

The *'unsafe condition'*, its cause and preventative actions were identified in an FAA internal worksheet addressing an intended Notice of Proposed Rulemaking produced in 2003. [122] The intention was to prevent *'the possibility of toxic odours and fumes from entering the flight deck or cabin area… which could result in the impairment of flight crew or passengers.'* The cause of the unsafe condition was listed as a *'design problem.'*

The UK issued the ADs due to impaired crew performance that could have been associated with oil contamination necessitating such odours to be regarded as a *'potential threat to flight safety.'* [374,379] CASA, on the other hand, enacted the first AD even though it considered the actions had already been undertaken by Australian operators and also enacted the 2nd AD in 2002 as the air-conditioning ducts could absorb oil and become a source of persistent air contamination. [377,380] The German AD cited oil leakage as possibly leading to *'harmful contamination'* of the cabin air causing intoxication of the flight crew.

In 2003, the UK CAA issued the third AD (AD007-04-2003) related to oil contamination, requiring the mandatory actioning of BAe SB.49-036-36019E Revision 4 for BAe 146/146RJ models dependent on modification status. [381]

The AD related to an improved APU inlet flexible duct using an improved metallic bellows duct as a replacement for the existing rubber duct. The original BAe service bulletin (SB.49-036-36019E) was issued in 1993 with compliance listed as *'optional'.* CASA followed suit soon after stating *'Contamination of cabin air due ingestion of oil from the APU bay is found to occur on the affected aircraft. This modification provides an improved seal at the aircraft – APU interface to prevent this.'* [382] The FAA issued a similar AD in 2004 stating: [383]

- *'This action is necessary to prevent air from the APU bay being ingested into the flight deck and passenger cabin resulting in poor air quality and, if the air is contaminated, possible incapacitation of the flightcrew and passengers. This action is intended to address the identified unsafe condition.'*

It was seventeen years from when the first service bulletins were issued in relation to oil fumes from the engines, APU or environmental control system before any were made mandatory by ADs. The first was issued by the UK CAA in 2001. However reports of hydraulic fumes in 1985 led to the issuing of a service bulletin by BAe (SB 21-24- 00543A), which was made mandatory by the UK CAA some months later. [384] The reason for the SB being issued in 1985 followed by the AD in 1986 was *'To improve sealing between hydraulic bay and passenger compartment'* with the reason given as *'Fumes from hydraulic bay have entered the passenger compartment when aircraft unpressurized, after hydraulic system failure'.* [385]

BAe advised in 1999 that '*A testament to our aircraft safety record is seen in this chart which shows the number of federal aviation airworthiness directives issued throughout 1998 and 1999. An airworthiness directive is issued by the regulators when they feel sufficiently concerned that a real or potential risk exists to the safe operation of the aircraft. I can also say that none of the nine airworthiness directives which were on the BAe146 aircraft are in any way related to cabin fumes or smoke-in-cabin incidents.'* [3]

In fact, the 1985 hydraulic fumes service bulletin did relate to fumes in the passenger cabin and immediately after the Australian Senate Inquiry, the first of the 3 BAe 146 ADs was issued as safety was at risk as BAe acknowledged in

SB 21-150/21-156, which stated: *'In the past, oil leaks and cabin/flight deck odours and fumes may have come to regarded as a nuisance rather than a potential flight safety issue. However whilst investigations are being carried out, oil leaks and cabin/flight deck odours must be regarded as a potential threat to flight safety, they should not be dismissed as a mere nuisance and should be addressed as soon as possible.'*

British Aerospace advised the Australian Senate Inquiry in 1999 that its aircraft were safe as in the millions of hours the aircraft had been in service, it had *'never had a fatality for technical reasons and that was the standard industry definition of safety'*. [3]

7.4 Discussion

In the mid 1940's, the US military saw the use of engine compressed air bled in quantities suitable for cabin ventilation and refrigeration as a *'fortuitous circumstance.'* The advent of gas turbine engines with the need for increasing operating temperatures necessitating the use of synthetic jet engine oils and awareness of toxicity concerns has been known about since at least 1950. Both the military and commercial aviation industry were aware of the need for toxicity studies with the first known studies undertaken by the US Military in 1954, finding that thermal decomposition of lubricants and hydraulic fluids exposed to temperatures to 600°F (315°C) were far more toxic in terms of mortality than those heated between 400-550°F (204-288°C). As such bearing and lubricant problems in turbine engines operating at high speeds and temperatures was a major issue for the military in the 1950s with non toxicity over the whole temperature range listed as one of the main requirements.

Early on, zero oil leakage considered chiefly necessary due to the common practice of using compressor bleed air to pressurize and supply air to aircraft cabins, was noted to be difficult to obtain under all operating conditions. Any oil leakage into the compressor air flow was able to cause serious cockpit contamination problems due to the formation of toxic fumes. The design and operational set up of oil bearing seals pressurized with air and responsive to variations in engine operating conditions, could lose performance fast when seal wear occurred or during certain thermal or transient conditions. Positive seals, such as carbon face seals requiring surface finish or flatness were known to involve excessive wear and leakage as heated oils led to a deterioration of the surface finish. The engine was therefore recognized as the main source of bleed air contamination and the extent of the contamination was governed by the oil leakage rate of the front compressor seals. However, while turbo compressors were deemed necessary to supply cabin air for breathing for the early jet aircraft given the limitations of early oil seals, the improvement in such seals has been interpreted to allow *'negligible'* amounts of oil leakage into the bleed air in current day aircraft, thus endorsing the use of bleed air.

Oil and engine manufacturers recognized that turbine engines with higher compression ratios, and more power and the need for reduced fuel consumption had forced temperatures of oils and bearings higher, with better oil compatibility with seals required if seal leakage was to be minimized. The higher operating temperatures and drive for greater fuel efficiency along with other engine design changes placed additional stress and higher heat loads on the lubricants, with improved ester base stocks and additives required and alternative synthetic lubricants sought as engine operational temperatures exceed the limits of the lubricants. However, leakage of oil into the compressor air supply is an expected but not an intended use and as such temperatures to which the oils are exposed in this scenario are greater than lubricant specified operating ranges. In the early 1960s most phosphate ester antiwear additives used in lubricants replaced TCP/TXP with alternative additives that did not contain TCP/TXP, given that tricresyl/trixylyl production was shown to be neurotoxic. However, the military and aviation markets were the two main markets that did not wish to replace TCP with the view being that the ortho content of TCP was very low.

While areas of the military undertook investigations and were reasonably open with their findings, on the civilian side, this has not been the case. The previous military findings have been ignored and in practice failed to lead to effective actions to reduce the contamination issues. Various actions and investigations were undertaken during the 1960s regarding the toxicity of the oil and control of contamination. Heated oil inhalation animal studies found gross changes leading to death as a result of severe respiratory tract irritation. The FAA concurrently undertook uncited studies attempting to isolate the thermal decomposition products that could be correlated to a safe threshold limit for humans. However, it was clearly recognized there was no safe threshold level set for synthetic oils and mineral oils threshold levels were adopted unofficially (and incorrectly) as a suitable safe level, despite being an entirely different product.

Industry interpretation of the toxicity studies remained an issue throughout the 1960’s, but were deemed to involve *‘no serious toxic hazard’* and assessed as an engineering problem involving a nuisance that needed to be eliminated by whatever means, engineering or otherwise. The US Navy, however, required crew breathing direct bleed air, to use 100% oxgen from take off to landing to protect against adverse effects. There was a strong push to take bleed air at higher temperatures/higher pressure stage of the compressor within the engines, as this would simplify pneumatic systems. As such, the investigations of the toxicity of bleed air taken at higher temperatures continued through the 1960s and early 1970s. It was at this time that oil contamination of the bleed air was described as a *'once serious problem'* that had been almost eliminated by the efforts of the engine manufacturers.

While earlier turbine engines using compressor air limited operating temperatures to under 700°F (371°C), seemingly based on the USAF 1954 studies, some manufacturer's guarded against the possibility of toxic products of the oil decomposition occurring in the air conditioning system by taking only low temperature bleed air. Some earlier bleed air aircraft used the higher bleed air extraction temperatures for short-term, hot day operations only, while the more advanced engines used higher compression ratios and therefore higher extraction temperatures, well above the accepted critical oil decomposition temperatures, during normal operations. Some operators minimized contamination during normal operations by using interstage bleed ports (low stage compressor pressure) to ensure bleed air temperatures almost always remained below the critical temperatures for the oils. However, more advanced technology engines using higher pressure ratios and temperatures resulted in bleed air extraction temperatures well above the accepted critical decomposition oil temperatures during most normal operating conditions. The original practice of taking air only from the low stage compressor to avoid toxic products of oil decomposition entering the bleed air, was overtaken by engine manufacturers enquiring about and eventually taking the air from further back in the compressor when more highly compressed and hotter with the use of high and interstage bleed air extraction ports becoming standard. Current bleed air extraction temperatures are said to range from 50-300°C (122-572°F) for the low pressure port through to 300-650°C (572-1202°F) at the high stage port, however, some may be higher. Some engines such as the BAe 146 ALF502 have limited the maximum bleed air extraction temperature to exactly 700°F

(371°C) and 310°C for the B757 Rolls-Royce engines, indicating health problems were an overriding issue. Thermal decomposition of the heated oils was viewed as the major concern with the chemical breakdown products altered from the original fluids. In the early 1980s, 320°C (608°F) was viewed by the industry as the temperature above which the oil breaks down into *'irritating and toxic compounds'*, however while irritation awareness remained after this time, all references to toxicity at these elevated temperatures were removed. Limited recognition that contaminant levels may individually not be that high but the un-researched synergistic effects of the heated oils may be the source of the problem, has remained an area involving no further study.

There are and have been (since at least 1953) numerous very clear aviation regulations addressing the requirement for clean uncontaminated air that are applicable to commercial transport aircraft directly addressing toxic and noxious, hazardous and harmful fumes and undue discomfort and fatigue related to the supply air. Purity of the air supply in terms of toxic products from the bleed air are required to be *extremely remote and improbable* with the safety analysis taking into account toxic products in the bleed air sufficient to impaircrew performance. Regulations also exist requiring systems to be designed to perform their intended functions under all foreseeable operating conditions. In addition to the regulations, the FAA required that in the event of lubricant bleed air contamination, the bleed air temperature would remain below the *'critical level'*, above which harmful contaminants begin to form or the exposure would be so short such that even with high leakage rates, no ill effects would occur in crew or passengers. It was recognized in the mid 1960s that civilian and military aircraft of the future would be unlikely to pass the FAA bleed air purity tests and the regulations given the use of hotter temperatures. The regulations regarding bleed air purity in the 1960s were seen as *'rather vague'* and it was assumed that the regulations would be revised and tightened up, however this has not occurred, despite the FAA admission that *'toxic bleed air'* was a *'unique hazard.'* [111] Additionally, the airworthiness regulations FAR 25.831 were assumed to be met in at least 1980 based on the earlier 1954 USAF toxicity studies indicating a total oil leak would expose humans to oil mists for 1.7 minutes only, therefore indicating bleed air heated to 700°F

(371°C) should not be unsafe for humans in an aircraft. The regulations are mistakenly interpreted to take into account CO, CO_2 and O_3 only, and the SAE non-mandatory bleed air quality specifications involve normal operations only, do not suggest limits for oil substances and are not to be interpreted as standards for breathing air. However, it is clear the industry intent was that under normal operating conditions, the bleed air should be free of *'engine generated objectionable odours, irritants and/or toxic or incapacitating foreign materials'* with such substances not generated to a harmful degree following any type of engine or component failure. As oil is not intended to leak into the air supply, such an action is a failure of the system as it was intended to be. Additionally, given that no aircraft has any form of contaminant monitoring equipment, the FAA has advised that no aircraft in fact meets the intent of the airworthiness regulation 25.831. Very importantly all synthetic jet oils required to adhere to MIL Spec standards must demonstrate that the oils have no adverse effect on human health when used for the intended purpose, that is in an aircraft environment in this case.

While short-term effects associated with the inhalation of the heated oils is recognized and toxicity studies related to the phosphate esters are acknowledged as incomplete, the major oil manufacturers have failed to undertaken inhalation studies of the heated oils in recent decades. However inhalation of oils in an aircraft cabin has been dismissed as an abnormal use, despite all risk assessments referring to normal use only. Additionally toxicity has been assessed in terms of OPIDN only, apart from recent studies undertaken by NYCO and university based researchers indicating other toxicity effects are occurring. However, Mobil has clearly acknowledged that *'the summation of results from an integrated testing program, plus human exposure evidence, provides the most reliable basis for making decisions on marketability and generating the health and safety precautions needed to protect those who come into contact with the products.'* [386] Despite clear evidence presented to Mobil that a wide range of health effects are occurring in an acknowledged oil leak environment, Mobil has insisted the only effects are OPIDN and transient gastrointestinal effects, [96,387] even despite it's MSDS advising otherwise.

There is a vast amount of documentation from within the aviation industry clearly indicating that the inhalation of synthetic jet engine oils, in an aircraft, are considered hazardous and not a normal, yet expected condition of use. When such exposures occur sufficient to cause discomfort, irritation or toxicity, the ventilation airworthiness regulations will not be met. The awareness and documentation extends back at least six decades indicating that exposure to contaminated air is not a rare occurrence, is hazardous, and has serious implications for flight safety as well as to human health. However contaminated air has been deemed as a nuisance rather than a flight safety and health issue. There has been limited but important recent recognition that individual factors, exposure to mixtures and exposure patterns can all influence susceptibility to adverse effects of contaminants, yet to date this has not been incorporated into risk assessments regarding exposure to contaminated air. Instead, contaminants continue to be assessed individually in terms of individual threshold limit values for the cold product.

Therefore, while there is clear industry recognition that oil, hydraulic and deicing fluids can and do enter the engine compressor and ECS and cabin, breaking down upon heating, the questions raised have been the frequency, degree of exposure and effects. In the years from 1950-1970, there was clear awareness that bleed air contamination was a major concern, particularly with increasing temperatures and higher bleed air extraction temperatures. However around 1970, the research and data available noticeably decreased, with only limited military research taking place and extremely limited civilian information available about any associated hazards. This coincided with the use of more advanced fuel efficient engines utilizing higher temperatures and the 1970s fuel crisis necessitating further fuel efficiencies and the introduction of recirculated air systems utilizing less (costly) bleed air. As bleed air extracted from the compressor and used for air conditioning before being exhausted overboard, is lost from the engine cycle, fuel consumption is therefore increased. [388] Therefore, recirculated air was introduced according to Douglas Aircraft Corporation to gain significant fuel savings (Congress request to NASA to reduce fuel demand), however the quality of the air *‘tends to decrease due to the entrainment of smoke and odours.’* [388] According to Douglas the optimum operating point was defined as the minimum rate of bleed air extraction for air conditioning that maintains a comfortable cabin.

Disjointed awareness of contamination and associated hazards occurred over the years from 1970 to the present day, generally not shared openly within the industry and dismissed as a nuisance and isolated infrequent problem. More recent publicly available investigations have in general minimized the concerns and have in all cases failed to take into account the early awareness of toxicity and design issues of using bleed air from engines. The vast amount of available documentation from the 1950's through to the present day has failed to be collated and reviewed in it's entirety, therefore missing the opportunity to recognize all aspects of contaminated air exposures and address the problems suitably, based on data currently available. No matter how much information is available, the industry has continued to fail to act on the hazardous findings and adverse effects that have been documented over the past 60 years. It has been suggested that industry corporate bias has allowed this problem to continue over many years since first highlighted. [389]

A case study review of the BAe 146/146 RJ aircraft highlights the extent to which some in the aviation industry have gone to manage a readily accepted problem.

The history of contaminated air on the BAe 146 goes right back to at least the commencement of flight on the aircraft in 1983 and even further back for the engine itself. It can be seen that the initial certification of the ventilation system simply looked at CO and CO_2 and the likelihood of oil contamination from an engineering viewpoint, despite the initial certification being required to ensure the system (other than simply CO, CO_2) was free of harmful and hazardous contaminants that could enter the ventilation system. The initial certification air airworthiness requirements need to be met as well as on an ongoing *'continuing airworthiness'* basis throughout the aircraft's operating life. [1,390,391] The evidence that crew and passenger discomfort was occurring along with the fact the air could not be said to be free of contaminants, indicates that the main airworthiness ventilation regulations were not met (BCAR -1976; JAR 25.831 a/b - 1979; FAR 25.831 a/b -1965).

The nature of the engine oil bearing seal problem is clearly acknowledged as a design issue which allows oil to leak into the bleed air supply as a function of design, as such a design flaw, or a design problem as acknowledged by the FAA. [122]

While in service, the issue of oil contamination will be viewed as a maintenance issue, it is in fact also a continuing airworthiness issue. However, the extensive list of service bulletins and other related data indicate it is an ongoing design issue. BAe acknowledged the ongoing design aspect in 2000 when advising that engine or APU seals may be less efficient during transients (engine acceleration, deceleration or while achieving an optimum operating temperature) and improvements in design, when available, would be provided. [261,262] However, given this is an airworthiness issue, the aircraft in fact are not airworthy whilst continuing to suffer this long, ongoing and clearly evident problem. Additionally once the air supply system is contaminated by the engine or APU, the bleed air ducts downstream must also be thoroughly cleaned to eliminate the oil breakdown products, yet the ducts cannot be cleaned *'in situ'* and must be removed to wash out the oil products, which involves major maintenance. The common use of the MEL system to allow an aircraft with contaminated bleed air defects to continue flying is contrary to the airworthiness requirements as the MEL system cannot be utilized for airworthiness or safety related items. The difficulties faced in identifying areas contaminated by bleed air contaminants by both crew and line maintenance are generally disregarded, particularly given there are no bleed air detection systems fitted to any commercial aircraft.

There are in excess of 220 various types of BAe 146 or 146/RJ pieces of documentation that have been collated by the author. These are generally not available for review and are difficult to source. This documentation often indicates problems in particular airlines, which are ongoing over many years. They also clearly highlight that the problems related to contaminated air are not limited to one specific area, but involve oil or hydraulic fumes contaminating the air supply in a host of different ways.

However service bulletins are only mandatory when the regulator adopts them as an Airworthiness Directive to address an unsafe condition. Despite contaminated air being an airworthiness issue and one that must be addressed for an aircraft to be considered fit for flight, most of the service bulletins were either optional, for information or recommended at a time in the future or even at the operator's convenience. Known problem areas have remained over many years. For example an improved No. 1 bearing seal was raised in at least 1992 as well as 2003, while a complete filtration system was raised in 1992 and again in 2010 as a new air treatment unit is being trialled. In the case of the new air treatment unit, this technology has been recently criticized as not being suitable for an oil contaminated environment. [392]

The Airworthiness Directives related to the BAe 146 were issued seventeen years after the first service bulletin identified the oil contamination problem. In the case of the hydraulic system SB, this was enacted as soon as the problem became evident as likely this was a manageable problem, whereas there was clearly far more information showing the scale and nature of the oil fume problem. The ADs were inappropriately not issued for the RJ and only one has been issued for any other aircraft type experiencing oil or hydraulic fumes. Such fumes are contrary to the airworthiness requirements in all aircraft and any ongoing problem must be seen as a safety risk and addressed via the AD system or alternative. The aviation industry view modifications and inspections for oil leaking into the air supply as part of its ongoing product improvement and enhancement, [3] rather than as a mandatory requirement to meet the airworthiness regulations. This is a fundamental flaw and clearly based on this case study, oil leaking into the air supply is an unsafe condition and correction should not remain as optional or similar. However, oil fumes were clearly regarded as a nuisance, rather than a flight safety issue and despite ongoing modifications to address the issue, the legal requirement for clean air was effectively ignored in order to continue operations. The ongoing nature of the design flaws allowing contaminated air to enter the air supply were isolated and minimised by the manufacturers, with individual airlines dealing with the problem as if it was simply an ongoing maintenance defect for which it sometimes sought the manufacturer's support.

Potential reasons for the extensive and protracted non mandatory SB history and the delayed action in regards to the BAe 146 AD implementation could relate to the fundamental question of accountability within the UK CAA and potential conflict of issue problems, with numerous former BAe senior personnel now working within the UK CAA. The UK CAA is in fact entirely funded by the industry it is tasked with regulating and the BAe 146 had it's origins as a state run project. Additionally, the entire aviation industry has failed to recognize that airworthiness issues such as clean air is not an optional extra and must be met and as such is a responsibility for the regulators under the Airworthiness Directive system. However the additional problems of the BAe 146/146RJ history regarding the oil contamination issue and the clear increased severity of the problem with this aircraft type and actions taken by the manufacturer and operators over the 25 year period have been in addition to the general industry problem of contaminated air faced by all manufacturers and operators.

Airline operators using the BAe 146 were aware of the fume problems right from the start with the earliest records relating to PSA in the United States in 1985, however the fumes were highlighted in service bulletins and service information leaflets the year before, in 1984, the first year of service. Numerous operators were experiencing considerable problems that they were quite vocal about from at least the late 1980s. However when Air BC asked BAe if other operators were having problems, they were advised this was not the case.

British Aerospace was aware of the problems involving its aircraft from very early on and undertook a variety of actions. Ansett as an airline operator was very aware of the problems it was causing its bottom line and engineering resources. Initially there was an attempt to suggest the problem was limited to the APU or 300 series fleet only, however it soon became apparent that it was an engine and APU fleet-wide problem.

Ansett spent considerable resources trying to get help from the aircraft, APU and engine manufacturers and noted considerable friction between the two. The problem was identified as the APU and then found to be engine related as well, which was in fact clear from the service bulletin history from 1984. A lot of actions were undertaken; however, they were reactive and did not address the underlying causes. It was clear that there were many crew experiencing adverse effects, however these remained unaddressed by the airline.

Confidential agreements were put in place in 1993, whereby Ansett/East West obtained money or similar from the engine, APU and airframe manufacturers for the adverse effects of contaminated air, however terms ensured the problem remained confidential and in effect unaddressed. Therefore, a major health and safety and flight safety issue was put aside so as to satisfy corporate objectives.

Ansett's manner of dealing with an occupational health and safety issue became very aggressive, manipulative and in fact led to a culture of deceit and denial as a consequence of the threat of legal actions which lasted until the company's collapse. British Aerospace and Allied Signal were equally as implicated and therefore this is not an issue related to a defunct airline, it is one for the whole airline industry. The problems evidenced in this case study are clearly continuing today within many areas of the industry and on other aircraft types, yet the industry has ignored the early awareness of the problem and downplayed and denied or minimized the problem. Therefore aircraft have been allowed to continue to fly in an unairworthy state with a clear design flaw, rather than addressing the real problems.

The aviation regulator's view that this is an OHS issue for which it is not responsible has allowed this problem to continue on to date. Recent actions as can be seen in Chapter 4 and elsewhere have been more an exercise of controlling the outcome than resolving the problem. Anything that can affect safety in flight is the responsibility of the regulators and cannot be left to those who have a corporate interest to resolve as can be readily seen from the case study. The aviation industry cannot be allowed to suggest the area of clean air in aircraft is outside its expertise. It should take the responsibility to address the problem which if asked, the travelling public and crews would have already assumed was occurring.

BAe advised that there was a standard industry level at which oil leaked into the air supply and that while in the early 1990s, it's aircraft leaked above the industry standard, actions undertaken had reduced leakage to the standard industry level. FAR 25.831 and the equivalent regulations require the air to be free of harmful and hazardous levels of contaminants. Without this regulation met, and with clear acknowledgment that oil was leaking and no detection equipment was fitted, the aircraft failed to meet the mandatory airworthiness regulations. Various actions have been undertaken as can be seen in this Chapter and in Chapter 4 to suggest that the air quality is acceptable and therefore the regulations are being met, however by looking at the extent of data available in this Chapter alone, it can be seen that this is not the case.

The systemic nature of continuing contaminated air involving the BAe 146 and 146/RJ aircraft and all aircraft using bleed air combined with the early awareness that the design of bleeding air from the engine compressor and operational set up of such systems, explains the nature and frequency of contaminated air. Therefore, this indicates that this is not simply an ongoing product modification as suggested by BAe and standard practise in the industry. This is a design and continuing airworthiness problem that must be addressed for an aircraft to be deemed airworthy and fit for flight. It is vital that all aspects of flight safety and OHS matters be regulated in such a way that corporate interests are never used to influence outcome, something, which has clearly been happening to the present day.

The aviation industry including the military has been directly aware of the implications and hazards for many decades, particularly given that this is a highly regulated industry and one in which information is readily shared. However, the need to keep aircraft flying, particularly in the civilian airline market has been given a higher priority than that of health and flight safety.

7.5 Conclusions

There are extensive data going back 60 years to the 1950s that show oil lubricants and hydraulic fluids used in aircraft can be hazardous and toxic. While leakage of such fluids at levels causing adverse effects is contrary to the airworthiness regulations and despite such leaks occurring far more frequently than acknowledged, the use of bleed air without adequate filtration or detection systems is deemed airworthy.

There was early military and civilian aviation industry awareness that gas turbine engines requiring the use of synthetic jet oils would become toxic when heated. As engine operating temperatures increased along with awareness that the design and use of bleed air systems allowed oil to leak into the cabin air supply, the concerns of toxicity were not eliminated, rather they were pushed aside in order to use more advanced turbine engines using the bleed air system. The higher heat loads, need for greater fuel efficiency and engine design changes have placed greater stresses on the synthetic lubricants, with TCP use in the aviation and military markets remaining two of the few uses remaining in the lubricant market.

The airworthiness bleed air purity (ventilation) regulations in the 1960s were seen as vague and as engines became hotter, aircraft were regarded as unlikely to pass the requirements. Odours, haze and irritants were seen as the warning to shut off a contaminated bleed air system, with such action assumed to be undertaken very quickly before toxic exposure levels were reached based on the 1954 military studies. It was assumed the regulations would be upgraded. However, based on 1980s documents the bleed air certification was still based on the 1950s assumptions and toxicity data and the regulations up to the present have in effect not been updated since the 1960s as assumed. The same warning system is still used as it was in the 1960s, which is the crew sensing fumes by odour by nose, as no monitoring equipment has been installed.

While some aircraft like the BAe 146 appear to have greater problems than others, all aircraft using bleed air are prone and known to have this problem. Although bleed air leakage is partly a maintenance and operational issue, for which some manufacturers suggest it is the airline maintenance and operational practices alone that are at fault, this is fundamentally a systemic design issue related to the use of bleed air within commercial and military aircraft. Numerous components in the system are not functioning or operating as originally intended, resulting in flaws in the concept of using bleed air. The Boeing 787 has been designed with a bleed free architecture, which may be the only real solution to this industry wide problem. If this proves to be the case, this would be ironic as all the first jet engine powered commercial airliners such as the Boeing 707, Convair 880/990 and DC-8 had also been designed in such a way that engine oils could not contaminate the air supply from the engines.

There is substantial evidence dating back to at least the 1950s indicating bleed air contamination was occurring, with crew impairment from leaking oil being documented with calls citing further investigation was *'definitely warranted.'* The flight safety implications and hazards of breathing these oils and fluids are well known, yet the corporate and government denial and then minimisation has enabled this problem to remain unresolved.

The BAe 146 provides a case study of an aircraft that was allowed to leak oil into the air supply from its inception. The aircraft and engine manufacturers along with airlines in the 1980s were well aware of this and took a large number of limited steps that did not adequately address the source of the problem. The problems were passed on to other operators of the BAe 146 and its successor with the assumption that optional individual modifications had fixed the entire problem and the extensive history of the problems faced, seen as unnecessary information. Considerable but ineffective action was taken, however it was inappropriate as the actions failed to address the whole problem at the source, were not made mandatory or overseen and were reactionary and divided. Attitudes moved from denial to damage limitation, confrontation and corporate responses at the expense of flight safety and occupational and public health. The problem was shifted from an engineering and design problem to one that then sought to blame and marginalise those who complained. This likely change of empasis most likely resulted from the realisation that the design flaw would never be corrected during the life of the aircraft and therefore a campaign of misinformation and denial had to be introduced to accompany the aircraft to its natural end of service life. The continuation of allowing contaminated air to routinely pass into the air supply and limited actions undertaken were endorsed by regulators and passed from one airline customer to the next. The extensive official documentation and company actions clearly demonstrate that they were able to operate outside the legal framework under the guise of product enhancement and keeping aircraft flying.

Had the initial problems on the BAe 146 occurred today in an age of global Internet and mobile phone communication, without doubt the aircraft manufacturer would have struggled to prevent the aircraft being grounded until a real fix had been incorporated into the engine and APU seal designs. Interviews by the author with members of the Australian Senate Inquiry Committee revealed that had they been made aware of all the data now available in relation to the ongoing contaminated air problem on the BAe 146 the committee would have most likely called for the aircraft to be grounded in Australia.

The use of the bleed air system was initially deemed unacceptable given the inherent problems in the design of oil seals. However, as the need to use bleed air for more advanced engines took over it was assumed actions taken by engine, aircraft and seal manufacturers had reduced oil leakage to negligible and therefore acceptable levels. The military has remained almost silent despite clear awareness of the toxicity issues. The commercial market has failed to collate the data and effectively ignored all evidence which indicates that contamination is not negligible, far more frequent than desired, is not a ground based workplace to which industrial safe levels can be applied, a design issue and anything beyond an irritant. To recognize such issues would require real and major change.

Many in the airline industry have suggested this is a problem for one or two aircraft types only. Clearly, available evidence shows that all aircraft using bleed air can and do allow contaminated air to contaminate the air supply. The continued industry culture of denial and marginalisation is contrary to the set legislations and cannot be allowed to continue.

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8 Discussion

8.1 Introduction

This chapter will review and discuss the various findings that have been highlighted in the individual thesis chapters and will demonstrate how all these areas along with the additional data reviewed are intertwined and play a critical role in aviation flight safety, occupational and public health. The various international perspectives will be reviewed along with international actions in light of these findings and solutions, will then be put forward by the author.

8.2 Discussion

The use of engine bleed air to supply air for crew and passengers to breathe allows synthetic jet engine oils, hydraulic and deicing fluids to contaminate the air supply by way of the design and operation of currently used bleed air systems. These products contain toxic ingredients, specifically irritants, skin sensitizers and neurotoxins with contamination often also occurring in a reduced pressure, hypoxic environment. When such exposures occur they may be to a mixture of unchanged or degraded oil/fluid or combusted or pyrolised oil/fluid in the form of gases, vapours or particulates (fumes, mists, aerosols). When such aircraft oils and fluids leak into the air supply, such exposures can jeopardize flight safety and health. This raises the question of occupational health and safety legislation and duty of care; while exposure to substances causing irritation, discomfort or toxicity contravenes the main airworthiness ventilation regulation, FAR, CS 25.831 a/b. Therefore, continuing airworthiness cannot be said to be met and the aircraft cannot be considered fit for flight.

The questions of how often such events occur, what contaminants can be released during these events, what effects such exposures can cause in flight as well as to human health, is crucial to the full understanding of the scale and nature of the problem. However, available evidence clearly supports the need for preventive actions to be introduced to enhance flight safety and protect crew and passenger health without further delay.

8.2.1 Health effects in aircrew

Two descriptive case studies were undertaken involving (mainly) pilots on the BAe 146 in Australia and the B757 in the UK, both short-haul aircraft. The symptoms reported were consistent with those previously identified in other studies and revealed a consistent pattern of effects.

A third more extensive study was undertaken for BAe 146 pilots in the UK over 4 years on a non self selected basis using a combination of interview survey techniques. Importantly of the 274 pilots in the survey, 238 of those consisted of working pilots with the remainder no longer retaining medical certification. Identifiable trends of pilots being unwilling to talk about contaminated air were evident as health effects are effectively denied by the airline industry and indicate operation contrary to aviation legislation. However, 274 past and present BAe 146 pilots or 14% of all UK licensed BAe 146 pilots were contacted with 173 (63%) advising they had experienced adverse effects that were considered relevant to the work environment by the author. 28% reported no effects, however there was strong evidence of pilots withholding health data as has previously been recognized within the pilot fraternity. 88% of the surveyed pilots reported confirmed exposure events to contaminated air (acknowledged as predominantly oil fumes by the manufacturer, CAA and others) with frequency of exposure more notable than one off more identifiable events. 63% reported adverse symptoms of a consistent nature while 32% reported medium to long-term effects and 44% reported immediate or short-term effects. 13% of those surveyed were no longer able to maintain pilot medical certification, were retired with consistent pattern of long-term ill health or deceased and considered possibly relevant, given an exposure history to contaminated air.

Of the 219 pilots who indicated adverse effects or no reported health effects, a range of neuropsychological, neurological, respiratory and cardiovascular, gastrointestinal, irritancy and general symptoms were reported in the immediate and short-term with a clear development into the medium or longer term for a considerable number of the 52% reporting specific symptoms. For example, the main immediate or short-term symptoms were upper airway irritation and breathing problems (17%) eye irritation and vision problems (10%), neuropsychological symptoms reported include performance decrement (13%), intense headaches (11%), memory impairment (10%), dizziness (10%), confusion (8%), fatigue and exhaustion (15%) and nausea (11%). These represent a considerable risk to flight safety. In the longer-term, the main symptoms reported were upper airway and respiratory symptoms (17%); cardiovascular symptoms (10%) such as palpitations, altered heart rate and chest pain, skin irritation, rash or blisters (8%); memory impairment (14%); performance decrement (11%); intense headaches (8%); tingling in the extremities and nerve problems (8%); exhaustion and fatigue (9%); with chronic fatigue (10%) amongst others, including the development of chemical sensitivity. The majority associated their symptoms with exposure to contaminated air, while all pilots surveyed are acknowledged to be operating in a contaminated air environment by the aircraft manufacturer. The pattern of long-term ill health in those no longer able to fly showed the same pattern of symptoms, with a smaller subset developing identifiably more severe neurological conditions and other conditions. This study was particularly significant, as it consisted once again of mainly non self selected working pilots.

There was sufficient commonality with the symptoms seen in the surveys along with a similar pattern on an international basis to support a symptom basis for aerotoxic syndrome. This conclusion was supported by an extensive exposure history, industry documentation and in the medium to longer term cases, medical records with all 3 case studies supported by other published studies. Features of this syndrome are that it is associated with aircrew exposure at altitude to atmospheric contaminants from engine oil or other aircraft fluids, temporarily juxtaposed by the development of a consistent symptomology of irritancy, sensitivity and neurotoxicity. These symptoms may be reversible following brief exposures, however following repeat exposures; a longer-term irreversible pattern is developing consisting of neuropsychological, neurological, respiratory/cardiovascular effects along with immune system effects, chemical sensitivity and chronic fatigue.

8.2.2 Air monitoring studies

A range of studies have been undertaken within the aviation industry reviewing air quality generally suggesting that the substances found are within set government standards or guidelines. Where contaminated bleed air substances leak into the cabin air supply, people will be exposed to the contaminants and there is the potential people may suffer subsequent adverse effects in flight and for health problems to arise. Evidence is available to show this is not infrequent.

A close review was carried out of the 53 air quality studies that are in whole or part publicly available and which undertook air monitoring. Of these, 62% of the studies were undertaken specifically looking at bleed air contamination, while 38% were assessing general air quality standards only and not using suitable techniques to detect bleed air contaminants such as oil. None of the specific bleed air studies were undertaken during a contaminated air event except for 1 sector on a B757 (Muir 2008) which experienced a *'minor'* fume event and still reported levels of contaminants below other aircraft on the ground not experiencing a *'fume event'*. Five of these studies undertook telephone follow up/medical record reviews, questionnaires and symptomology collation, however not during the monitoring. 27 % of the specific contaminated air event studies suggested the air quality was acceptable, however strong industry bias was demonstrated.

Of the general air quality studies, 60% suggested the air was acceptable with all again showing strong industry or Government bias. Eight studies undertook limited epidemiological reviews ranging from surveys in most studies to limited physiological reviews in two. However, techniques suitable to detect contaminated air were not used and the aim was not to assess bleed air contaminants. However, the general assessment that air quality was satisfactory was still made.

TCP was identified in 48% (16) of studies assessing bleed air for contaminants. These date back as far as 1988 to military studies, to more recent aircraft monitoring and TCP swab test studies. 64% (21) of the bleed air contamination studies identified oil as the source or part source of the problem. One of the major manufacturers provided false data on its TCP findings at the same time as finding contaminants 4 times above its own acceptable limits.

Studies of the oils have been undertaken over many years indicating upon combustion and pyrolysis, a wide range of compounds can be found, many of which are breakdown by-products of the heated oils and are toxic. A select few studies [1,2,3,4,5,6,7,8] of air quality or aircraft ducting (not undertaken during a fume incident) have found a wide range of breakdown products including toxic, irritating and sensitizing substances. The substances identified contain a complex cocktail of pyrolyzed chemicals, which would upon exposure produce a synergistic effect on those exposed; however these have been in all cases minimized by those having undertaken the studies. It is relatively unknown that the USAF undertook inhalation toxicity studies of the heated oils as far back as 1954, and upon heating, esters, aldehydes, carbonyls, CO and undecomposed particulate matter were found and in the case of TCP, free cresols, undecomposed TCP and CO were found. The toxicity of the products arising from the thermal decomposition of the synthetic lubricant was derived largely from the base stock and increased significantly at and above 600°F. Such temperatures (315°C) are frequently encountered within modern jet engines.

Studies not undertaken during contaminated air events cannot draw suitable conclusions that the air quality is acceptable and cannot therefore be said to not cause adverse effects, however this is very often the case. Most studies have failed to undertake epidemiological or individual case study reviews and those that have taken place have not been suitably undertaken, unbiased or thorough and generally not during contaminated air monitoring. The contaminated air monitoring studies have on the whole been unsuitably undertaken, including: not during a fume event; on the ground; using unsuitable techniques or measuring the wrong contaminants. All studies that have been undertaken have inappropriately referred the individual substances found to ground based exposure standards and failed to take into account the unique aircraft environment in which exposure to heated oils, fluids and the degradation/pyrolysis products are occurring.

8.2.3 Frequency of contaminated bleed air events

There is very clear aviation legislation that addresses all aircraft defects including suspected contaminated air events. These should be reported so that an investigation can be made and to prevent the aircraft continuing to be operated in an un-airworthy basis. However, there is a long history of bleed air contaminated air events occurring in the aviation industry and most of these events are not reported. By the very nature of the design of how bleed air is utilized, bleed air exposures will occur. The airline industry in general, suggests that contaminated air events are rare. Many suggest that the issue is only relevant when a seal failure occurs, however there is significant evidence and a growing realization (even by the FAA/EASA) that the true level of such events cannot be determined, as crew and airlines are failing to report these events as required. Research clearly shows that fume events are in fact anything but rare and a threat to flight safety. The regulatory reporting system is not working and the airline industry is continuing to ignore this, allowing contaminated air events to continue to be seen as a nuisance, despite many suggesting they do now see this (correctly) as a flight safety issue. There are a variety of reasons for this occurring, including lack of education and awareness about the health and flight safety consequences of exposure to contaminated air in flight; job security fears with a problem that has gone on for decades; a problem for which there appears to no real engineering solution and commercial pressures applied on those who have a duty to report such events. A pilot is unlikely to risk identifying adverse effects and health issues that could be related to the working environment, when such effects would be contrary to medical certification. The level of in flight impairment is high and the subsequent flight safety consequences can clearly be seen. The airline industry views safety in terms of aircraft getting from A to B without fatalities for technical reasons. [9] Additionally there is a culture of minimising flight safety and health risks associated with the design flaw of using bleed air. Inadequate precautions are being applied to prevent the health and flight safety implications for anyone breathing contaminated air in aircraft, whether they are crew or passengers. Contaminated air events occur far more frequently than the airline industry admits and most (less than 4%) events will never be recorded. To try and quantity the frequency of contaminated air events is inappropriate, especially when the industry itself has not fitted detection systems to monitor the air quality onboard, yet the airline industry continues to do so. This is a design and operational issue involving the expected leakage of air and oil given the use of engine oil seals in the bleed air system. As EASA and the FAA recently advised respectively, the vast majority of fumes are related to oil and under-reporting is occurring. The use of bleed air systems, oil seals and expected leakage of oil and wear of the seals allowing leakage of oil is a very different issue to the occasional full seal failure.

8.2.4 How long has the airline industry known about bleed air contamination?

There is extensive data going back to the 1950s that oil lubricants and hydraulic fluids used in aircraft can be hazardous and toxic. The use of bleed air from the engines to supply air for the cockpit and cabin provides the means for the oils and fluids to leak into the air supply. While leakage of such fluids at levels causing adverse effects is contrary to the airworthiness regulations and despite such leaks occurring far more frequently than acknowledged, the use of bleed air without adequate filtration or detection systems is viewed by most, inappropriately, as airworthy. While some aircraft such as the BAe 146 appear to have greater problems than others, all aircraft using bleed air are prone to this problem. This is essentially a design issue for which there are numerous differing aspects of the whole bleed air and oil bearing seal system, in addition to specific maintenance practices.

There is very substantial evidence dating back to the 1950s indicating bleed air contamination was occurring, with crew impairment from leaking oil recognized as occurring from this time. The first known well documented case of exposure to synthetic heated oil fumes was documented more than 30 years ago, citing further investigation was *'definitely warranted.'* The hazards of breathing heated synthetic jet oils were recognized by at least 1954, with concern about the use of more advanced turbine engines operating at significantly higher temperatures and therefore the increased toxicity associated with exposure to the heated oils in an environment where leakage of oil was anticipated and expected. Interestingly, there was considerable awareness along with research that identified toxicity issues and concerns up until around 1970, yet since this time, this very significant awareness and data appear to have been forgotten in favour of engines operating at higher temperatures for economic and operational reasons. Limited references to toxicity and contamination continued, however the studies over the last 2 decades are incorrectly based upon the assumption that no information was previously available and little problem if any exists.

Engines operating as intended, leaking 'lower' accepted amounts of oil as a function of the use of engine oil seals as a part of the bleed air system, have become to be seen as normal, with the oil leakage ignored by virtually all. Only a more noticeable contaminated air event due to wear or complete seal failure is seen as abnormal or an episodic event. Therefore the far more routine 'lower level' leakage has become acceptable and in effect ignored.

Synthetic jet oils are being used outside their intended use as oils should remain in the engine and should not leak into the breathing air and therefore were not intended to be subjected to the temperatures they are exposed to in the engine compressors. As such, oils are being stressed beyond their intended limits. However while oils should not leak, the use of bleed air and oil seals by design indicates they will and do leak.

The flight safety implications and hazards of breathing these oils and fluids is well known, yet the corporate and government denial has enabled this problem to remain unresolved.

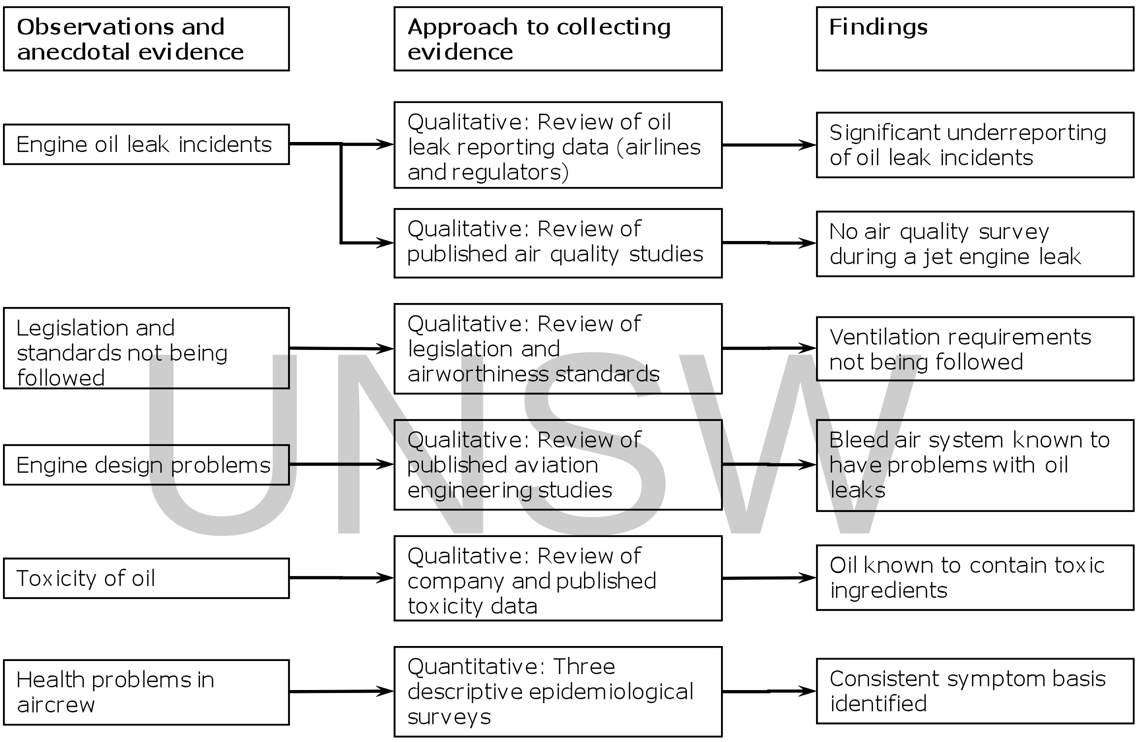
The BAe 146 provides a case study of an aircraft that has been plagued with contaminated air problems since it first entered service. The aircraft and engine manufacturers along with airlines in the 1980s were well aware of this and took a large number of limited steps that did not address the source of the problem. The problems have been passed from operator to operator with new operators no doubt assuming that individual modifications had fixed the entire problem. The extensive history of the problem was most likely never revealed to new operators. Considerable but ineffective action was taken, however it was inappropriate as the actions failed to address the whole problem at the source, were not made mandatory or overseen and were reactionary and divided. Attitudes moved from denial to damage limitation, confrontation and corporate protection at the expense of flight safety, occupational and public health. The problem was shifted from an engineering and design problem to an individual human problem that ignored the real consequences occurring in terms of health and safety. The continuation of allowing contaminated air to routinely pass into the air supply and the limited actions undertaken were endorsed by regulators who have failed to regulate. The extensive official documentation and company actions clearly demonstrate that they were able to operate outside the legal framework under the guise of product enhancement and keep the aircraft flying.

Many in the airline industry have suggested this is a problem for one or two aircraft types only, however evidence is available to show all aircraft using bleed air can and do allow contaminated air to infiltrate the air supply and such attitudes are a continuation of the culture of denial and operation, contrary to the set legislation.

8.2.5 Exposure to aircraft contaminated air

Figure 8-1 below demonstrates the key mixed methods approach used in this thesis and upon review indicates that the use of both qualitative and quantitative data serves the purpose of reviewing the various aspects of the contaminated air issue and therefore the true scale of the problem. The qualitative data has been collated data to support or refute the theory that contaminated air is a significant problem.

Figure 8-1: Key Mixed Methods, as Used in this Thesis



Engine oil by the use of bleed air systems will and does leak into the cabin air with very significant under-reporting of such events occurring. The oils are known to contain toxic and hazardous ingredients and monitoring of cabin air has been inadequate and cannot be used to suggest the acceptability of the air quality and associated health and safety effects. The aviation industry, regulators and Governments have in effect accepted that legislation related to clean air and associated health and safety legislation is not required to be adhered to. No control measures are adopted to determine if required standards have been met or not, in terms of air quality or bio monitoring.

In the case of qualitative data, the three descriptive epidemiological surveys and associated health data support the theory that exposure to aircraft contaminated air is not healthy, with a discrete occupational syndrome developing.

It is only by undertaking the above mixed methods of data analysis that the true extent of the problem can be seen and how the problem has evolved and continued. Essentially the use of bleed air in military aircraft was seen as fortuitous in the mid 1940s with civilian usage following soon after. Toxicity issues were raised early on as exposure to heated synthetic jet oils was expected and assumed safe as long engine temperatures remained low. However, there was awareness that engine operating temperatures would increase for economic and operational reasons and as this occurred, the toxicity issues were forgotten for several decades by the airline industry and they remain forgotten. As oil by a feature of the design of using bleed air is expected to leak, the frequency of leakage is inappropriately misunderstood as leakage is a part of the engine operation, seal wear is another expected outcome and full seal failure is correctly expected to be rare. Therefore this is an engineering design issue, with adverse health and flight safety implications that have effectively been minimized or ignored.

The airline industry has recently suggested that early turbo jets did not take the air into the cabins via the engines due to the unreliability of the engine oil seals. The industry incorrectly and inappropriately suggests that more recent engines do use direct bleed air via the engines due to the advances in oil seal design and technology to the extent that oil contamination is now *‘negligible’.* Such a statement clearly is used as a justification of the continued usage of a flawed system and one that very inappropriately ignores the evidence that is available indicating leaks are not *‘negligable’* and have serious consequences.

A select few authoritive bodies (military, manufacturers, SAE…) in the aviation industry recognized the hazards of breathing contaminated bleed air long ago; however no action was taken to address the problem. The focus for decades has been on denial of the problem and the insistence that there are no suitable data, along with individualised limited immediate fixes for select aspects only. The industry actions have moved from individual airline/manufacturer control of the problem in an effort to keep their aircraft flying to international acceptance that there may be a problem that needs further investigations. Select industry and Government stakeholders effectively dominate the international debate.

The Australian Senate Inquiry in 2000 led to a number of further inquiries and investigations at Government levels such as the NRC, House of Lords inquiries and further regulator/Government led investigations (COT, ACER, CASA EPAAQ, EU air quality standards, EASA A-NPA) and in some cases research. However these have been essentially industry dominated to date and have relied upon a close industry/Government alliance to enable the problem to continue on and be addressed in a manner and timing to suit the airline industry. These investigations and research effectively ignore the data that do not suit them; suggesting scientific research (that generally does not exist) is preferential over what they deem lay and anecdotal evidence that upon a broad review is accurately and professionally documented. As an example, the heavily industry funded European cabin air quality standards being developed do not address contaminated air, while the ACER work is focusing on select industry dominated aspects only without acknowledging the extent of the issue and failing to address the core problems. The UK COT committee on the other hand ignored much available data, relying heavily on industry vested interests to suggest there was not suitable evidence to address the contaminated air issue and indicated that further research to monitor the air was required. It was concluded that until it was known what was in the cabin air no action could be undertaken, however monitoring studies inappropriately undertaken and analysed will not identify the problem and the situation is set for no further suitable actions to be undertaken with the problem continuing. Therefore while the issue has reached the international level, it is at the international level being heavily managed by industry and government interests without the use of credible, truly independent expertise taking into account the true nature of the problem. In the interim some manufacturers (BAe) are developing technology that they advise will resolve the problem and is available for the international airline market, yet such technology has been found inappropriate to address oil fumes and other contaminated air substances.

8.3 What are the solutions?

The solutions to address the contaminated air problem do in fact exist and could be implemented if there was a will to operate aircraft in the intended airworthy manner. They cover numerous different areas including:

- Synthetic jet engine oils and other fluids should be assessed for overall toxicity of combined pyrolysyzed by-products rather than individual chemicals in a manner in which exposures mostly occur, that is via inhalation. Research should also focus on specific areas such as TCP and TAP biomarkers of exposure and polyol ester based synthetic oils should be assessed for toxic by-product creation such as TMPP, inhalation toxicity of other TCP and TAP isomers (non ortho) and similar;
- Ester based base stocks must be investigated for inhalation toxicity exposure at high temperatures as used in engine compressors;
- Establish standards and control measures for all contaminants suitable for the cabin air environment and the heated mixture of contaminants, rather than individual ground based standards;
- Exposure limits should be re-evalauted to provide protection to the most vulnerable sub groups that include the young, the infirm, the unborn, the pregnant and those who may be genetically more at risk from potential exposure effects etc.;
- Establish suitable biomonitoring and other techniques able to identify exposure to contaminated bleed air;
- Better designed engine and APU oil seals and bleed air systems that do not allow oil to leak;
- Appropriate engineering practices should be introduced to ensure leaks are addressed in a manner that ensures further contamination cannot occur when reported. MELs should not be applied where downstream contamination will have occurred;

- As clean air is an airworthiness issue, ongoing defects addressed through service bulletins should be made compulsory by way of airworthiness directives or alternatives;
- Clean air under FAR/CS (EASA) 25.831 *'a'* and *'b'* must be immediately regarded as part of the ongoing aircraft certification requirements as was originally intended. This must address all contaminants using standards suitable for the cabin air environment and the heated mixture of contaminants, rather than individual ground based standards;
- TCP should not be used as a substance in synthetic oils used in engines using 'bleed air'. Use of less toxic oils and fluids should be developed, mandated and introduced;
- Information on jet oils should be revised to accurately advise users of the true nature of hazards to exposure to jet oil and fluid mists, fumes and vapours and how these hazards can be controlled and prevented;
- Development of effective bleed air filtration or bleed air cleaning systems should be introduced on current non *'bleed free'* aircraft;
- Installation of effective bleed air detection (real time monitoring) systems identifying suitable markers to detect contaminated air should be introduced in each bleed supply line. This will alert crews when contamination is occurring and aid engineering with subsequent fault diagnosis;
- All suspected contaminated air events must be reported as an aircraft defect to the regulators and be made available to crew and the public. The appropriate aviation legislation must then be adhered to and enforced;
- The industry should stop trying to rationalize the extent of the contaminated air problem in terms of the number of bleed air reports as the reporting system is not working;
- Crews must use oxygen whenever contaminated air is suspected and passengers should be protected from exposure;

- Education for the entire industry that exposure to contaminated bleed air is a flight safety hazard and health issue;
- Organizations within the airline industry must accept their OH&S responsibilities under the legislation with clearly identifiable appropriate systems to ensure the legislation is met;
- Risk assessments must be inclusive of workers and passengers rather than excluding such vital data;
- Aviation regulators and OH&S regulators must both use their expertise to address the bleed air issue and must not defer responsibility to the other without suitable expertise;
- Research should be undertaken into the health effects associated with contaminated bleed air using case control studies and expertise free of industry/Government alliances.
- Workers who report adverse effects from bleed air should be appropriately investigated including the use of biomonitoring techniques;
- Individuals who have been exposed as crew or as passengers should be made aware of this fact. Details of the chemicals they have been exposed to should be provided to them so as to enable their physician to be able to treat and monitor their health appropriately;
- Health systems should be developed to identify and treat people exposed to contaminated bleed air and treat them with respect;
- International utilization of the FAA funded OHRCA medical protocol should be introduced while further research takes place;
- Establishment of an international database to report adverse effects of exposure to assist with international research to better understand the diversity of illness associated with contaminated bleed air; 'Aerotoxic Syndrome';
- Establishment of an international database to record contaminated air events to assist with international understanding of the issue and required actions;

- Better systems should be identified to monitor, detect, diagnose, treat and compensate affected workers; Those affected to date require industry level compensation, rather than individual legal actions that fall prey to the issues identified in this thesis;
- All future aircraft should be designed in a ‘bleed free’ manner as is the case with the Boeing 787 Dreamliner.

Independent expertise to date along with much available data has identified the link between adverse effects and contaminated air based upon the balance of probabilities.

For any studies in the future to be of any value, they must be undertaken by truly independent organizations with complete access as required, free of government and industry dominated alliances, corporate profit and conflicts of interest. Until this happens the industry is at liberty to effectively remain in denial or undertake actions that are exclusively aimed at managing an unmanageable situation until new technology can be introduced.

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9 Conclusions and Recommendations

9.1 Thesis Conclusions

In 1962, John Tukey, writing about the future of data analysis, wrote: Far better an approximate answer to the right question, which is often vague, than an exact answer to the wrong question, which can always be made precise. [1] Therefore this thesis using mixed methods of data analysis has raised a number of specific questions as follows:

What health effects are being seen in crew exposed to contaminated bleed air?

The answers to this question are:

- 63% of aircrews reporting an extensive history of exposure to contaminated air are reporting immediate to long term symptoms including irritation, respiratory and cardiovascular, neuropsychological, neurological, gastrointestinal, chronic fatigue and sensitivity symptoms; A further key, chronic ill health pattern has also been identified in a smaller subset;
- 44% of crews are reporting immediate and short-term effects, while 32% are reporting medium to long-term effects with 13% no longer able to fly;
- There is a close temporal relationship between exposure and ill health supported by extensive documentation;
- Oil/fluids leaking into the air supply represents a significant flight safety issue and major occupational health and safety as well as a public health issue relevant to both crew and passengers including the unborn;
- There is sufficient commonality in the health effects to justify the use of the term *'Aerotoxic Syndrome'*, as discreet occupational syndrome. Passengers can also be effected as they breathe the same air;
- Contamination of the cabin air sufficient to cause symptoms of irritation, fatigue, toxicity or discomfort indicates that the aviation airworthiness ventilation legislation FAR/CS 25.831 a/b is not being met. Therefore the aircraft is not airworthy.

What monitoring has been undertaken, what was found and can such data be used to assess exposure impact on human health?

The answers to this question are:

- Numerous cabin air monitoring studies have been undertaken, however many have been undertaken which have not monitored specifically for contaminated air;
- Studies have almost entirely not been undertaken during contaminated air events;
- Studies attempting to measure oil and fluid exposures show major methodological inadequacies and limitations so as to render their conclusions invalid. Interpretation of results has been inappropriate;
- These studies cannot be used to suggest that the air quality is acceptable and therefore not related to adverse effects;
- There are limited data available indicating exposure to contaminated air can have adverse effects;
- Strong industry bias is evident by many suggesting air quality is acceptable.

How often do contaminated bleed air events occur and what are the flight safety implications?

The answers to this question are:

- Bleed air leaks will occur with the use of current bleed air systems: all oil bearing seals leak as a function of design and operation along with wear and failure;
- Oil seal leaks apart from failure (wear and design features) are seen as normal and generally accepted and ignored;
- The vast majority of fume events are related to bleed air contaminated by synthetic engine oil;
- The true extent of contaminated air events is unknown as under-reporting is common and is acknowledged as occurring; pilots are failing to report all

contaminated air events as required; airlines are failing to pass reports on to the regulators and most events are not investigated adequately;

- The true extent of contaminated air events can not be known as there are no detection systems in aircraft;
- Bleed air contamination is far more frequent than the industry acknowledges;
- The airline industry relies upon a reporting system that is not working to avoid acknowledgement of the true extent of the problem and therefore actions required;
- Contaminated air events are not accurately reported on a central database and information is not looked upon as a whole to gauge accurate trends;
- The level of inflight impairment is high and presents a major flight safety risk.

Have the aviation industry and Government's dealt with the contaminated bleed air issue appropriately?

The answers to this question are:

- The aviation industry has been aware of the adverse effects of breathing jet engine oils and fluids since at least the 1950s;
- There are extensive data showing strong industry awareness of the dangers of breathing contaminated air;
- It has been known since 1954 that oil exposed to temperatures of 600-700°F is far more toxic via inhalation than oil exposed to temperatures of 400-550°F. Such temperatures are routinely used in turbine engines used today. The awareness of the increased toxicity with temperature has been essentially ignored by the aviation industry;
- Early awareness that oil leaked as a feature of using bleed air and would become toxic with raised temperatures was minimally investigated until the early 1970s, then as engine operating temperatures increased the toxicity concerns were forgotten and subsequently denied by most;

- Some bleed air temperatures appear to have been limited in maximum temperature based on oil toxicity factors, despite denial of toxicty, while other engines operate well beyond the *'critical temperatures'*;
- The 'critical temperatures'; identified in 1954 do not suggest toxicity cannot occur below these levels;
- 1960s awareness that more advanced engines would be unlikely to pass airworthiness ventilation requirements assumed legislation would be updated, however this has not occurred and aircraft do not meet the legislation as predicted;
- Many in the airline industry and Government alliances have gone to great lengths to ignore the data indicating the hazards of exposure to contaminated air with some having paid money and manipulated data to ensure that the problem remained hidden;
- The contaminated air problem is a hidden issue that is passed from one operator to another with the full history remaining hidden and unaddressed;
- The airline industry is aware contaminated air is contrary to airworthiness requirements and many regulations including OH&S legislation are not being met, however the legislation has been ignored, with the industry and Governments continuing trying to manage the problem or ignore it;
- Previous individual manufacturer or airline attempts to manage the problem have now been overtaken by major international alliances including Government, manufacturers, airlines and regulators with a pre-determined position.

What are the effects of exposure to contaminated bleed air?

The answers to this question are:

- Oil and fluids leaking into aircraft air supplies contain toxic ingredients which can be at a minimum irritating, neurotoxic and sensitizing;
- Synthetic oils leak as a function of using bleed air and when exposed to temperatures above 600-700°F (315-371°C) the breakdown products and

other substances become far more toxic than at lower temperatures. These temperatures are a part of the normal operating temperatures for today's jet engines.

- Information supplied by oil manufacturers to the manufacturers and airlines understates the toxicity of the oils, with such information accepted uncritically and used by manufacturers, regulators and airlines in a way that greatly understates risk;
- When oils or hydraulic or deicing fluids leak into the bleed air, crews and passengers do not have access to appropriate information that can advise them of the hazard, risk or control of exposure;
- Crews and passengers are not provided adequate information about the risks, hazards or controls about exposure to contaminated air or appropriately advised when contaminated events have occurred;
- Oil and hydraulic fluids leaking into the bleed air may occur in the form of unchanged, degraded, combusted or pyrolised oil or fluid and may be in the form of gases, vapors, mists and particulate matter;
- Where exposures may be to mixed forms of contaminants, an additional component of toxicity exists whereby irritant or toxic vapours or gases may be adsorbed onto the surface of mists or particulates. Under such circumstances, the dose response characteristics of the gas or vapour may be altered.
- Crews and passengers breathing contaminated bleed air are exposed to serious inflight safety hazards and their health may be affected both short and long term;
- The use of ground based exposure standards (TLVs) must not be applied to the aircraft environment;
- Chemical exposures at altitude must take into consideration the interaction of reduced pressure/oxygen, skin exposure to aerosols (mists and fumes) and the interactions of other contaminant exposures when inhaling a mixture of heated chemicals;

- In flight safety hazards of crew breathing contaminated air can lead to pilots being unable to operate the aircraft and cabin crew unable to undertake their duties;
- Crew experiencing discomfort, fatigue or toxicity after breathing contaminated bleed air renders the aircraft unairworthy and can lead to adverse health effects of a short and long-term nature.

It is a fundamental principle of OHS legislation that the employer has an obligation to provide and maintain a workplace that is safe and free of reasonably foreseeable risks to health. Where foreseeable risks are identified, a risk assessment should be conducted to establish the acceptability (or otherwise) of the risk.

For the research conducted in this thesis, the answer to the question: Are jet oil leaks foreseeable? is: Yes. The oil is toxic, oil leaks are being reported, and health effects in exposed crew are occurring. However, the aviation industry seems to be acting as if the answer to this question, is No.

The airline industry although aware of the contaminated air issue for over 50 years has gone to great lengths to ignore the issue and isolate contaminated air events where they occur and find ways to minimize and ignore the core issues. The military likewise has been well aware of contaminated air and although there has been periodic research undertaken, this has not led to solutions to prevent the problem.

The military and manufacturers were aware early on that compressor bleed air temperatures would rise and have risen for economic and operational reasons. They were also aware that the thermal decomposition, of particularly the oil base stock (and additives), would become toxic at elevated temperatures and far more toxic at temperatures above 600°F (315°C). There was acute awareness that such temperatures would become routine and part of normal operation and therefore there was the need to investigate bleed air purity and how to meet the airworthiness clean air regulations.

The 1960s toxicity concerns in terms of airworthiness clean air requirements were well founded, predicting what subsequently occurred with engines getting hotter. The legislation was seen as vague and actions undertaken such as isolating the contamination source in a short period of time to contain toxicity are inappropriate. In reality the prediction that more modern engines utlizing hotter temperatures would not meet the required standards, is the case, however the industry has ignored this little known key issue. Nothing has changed in 50 years in terms of clean air requirements and the toxicity referenced in the 1950s has been ignored as temperatures rose above the inconvenient toxicity range of 600°F (315°C). The regulators likely are no longer aware that such data exists as they likely have not looked or felt the need to look into this issue.

Some manufacturers appear to be aware of the 600-700°F (315-371°C) toxicity 1950s military data and it is assumed that the high bleed air port temperature limits are based on these toxicity factors, even though toxicity is not acknowledged. For example the ALF 502/507 engine bleed air port is limited to exactly 371°C (700°F), while the B757 high stage port is set at 310°C (590°F), yet other engines operate the high stage bleed air well above such temperatures. However, importantly the military inhalation studies investigated time to death and found severe adverse effects upon test subjects exposed to the higher temperatures. This is not an acceptable end point for crew and passengers in flight.

This highly regulated industry, which prides itself on safety and openly states it shares (selected) information within the industry, has clearly assumed clean air was an option in aircraft and not a safety concern. It has incorrectly assumed the legislation did not require the air to be free of all contaminants at levels that could produce adverse effects other than those listed by the regulators (CO, CO_2, O_3). Therefore the need for clean air has been ignored, as has the law. This view is further supported by the fact that the legislation requiring the air to be free of set levels of CO, CO_2, O_3 cannot be said to be met as the industry has refused to fit detection systems to aircraft to ensure these levels are met. According to the FAA, there was agreement (after the 2002 NRC report) within the industry that filtration mechanisms and a monitoring system are part of the requirements to ensure compliance with the ventilation regulatory legislation (25.831). [2] However such agreement has since been ignored and strenuously denied by virtually all parties involved.

The industry rather than fit detection systems, has now turned from denial to institutionalized co-ordinated responses to ensure the limited monitoring that is undertaken, is done in such a way so as to ensure they control the outcome. Either way, undertaking inappropriate monitoring, or most certainly inappropriate analysis accomplishes this aim. This key action is central to maintaining control so as to ensure actions required to address the real problems are either minimal or non-existent.

The industry and Government alliances have placed far higher emphasis on scientific knowledge, even if it is of little relevance to the core issues, over the extensive data that is available that has not suited the industry such as: data collated by aircrew and representatives; independent experts; independent published papers and extensively documented information. To this extent, almost all industry documentation (dating back to the mid 1940's) specifically showing the design and operational basis of oil leakage and ongoing nature of the problem has also effectively been isolated and ignored. This reliance on industry selected scientific data and research demonstrates a bias against employees and the public, with the airlines, regulators, government and manufacturers failing to acknowledge the issue and proactively respond. [3] This industry bias supports a scenario of *'creating of conditions'* [4] in which aircrew and passengers are accepting damage to their health and compromising their flight safety, [3] with the dominant stakeholders (industry) placing more emphasis on creating and continuing these conditions than addressing the core issues.

An additional issue is the USAF recognized problem of getting pilots to accurately address the issue of adverse effects when they have *'a profession, hobby or aircraft investment to protect'.* [5,6] This issue could also be relevant to cabin crew needing to protect a certain lifestyle and passengers placing their next affordable trip above their health and safety needs.

The statement by a senior official at the NTSB suggested regulation is undertaken by counting tombstones. [7] In essence, changes to air safety are only made when a cost benefit analysis is undertaken in which the cost of the new safety measure is balanced against a notional figure for the monetary value of a life. If the cost of the measure exceeds the *'value'* of the lives saved, the change will not be implemented. [7] It would appear little value is placed upon disability of aircrew and passengers in respect of contaminated air and the data are not assessed anyway. Therefore, there is little incentive for industry to address the issue of contaminated air. Crew and passengers should not be treated like *‘expendable items’* blamed for their illnesses and cast aside to then be replaced by others, [3] until an accident occurs that definitively proves cabin air was the cause.

There is no doubt flight safety has been frequently adversely affected in relation to exposure to contaminated air. The exact extent to which the contaminant cocktail may have impacted the complex decision making required in aviation cannot be accurately determined as there are no detection systems fitted to commercial transport aircraft and therefore no data to correlate with consequences. Any accident that may have occurred would be assumed human error and never related to contaminated air. The 1999 Malmo incident clearly shows that a fatal accident resulting from crew exposure to contaminated air exposure is very plausible.

The extent to which some in the industry have gone to avoid fitting detection systems can be seen in two UK government admissions: The first being when asked about fitting detection systems to all commercial aircraft, the response referred to proposed European legislation for the use of CO detectors on *‘single-engined aeroplanes with forward mounted engines’.* [8] The second statement that there is still a *‘need to establish whether there is contamination from the engine oil into the cabin’,* [9] clearly demonstrates a position of not having been willing to look at the vast amount of data already available, including the express acknowledgment of contamination and toxicity in 1954 by the military.

The extent of the available evidence in itself is overwhelming and the systemic marginalisation of a major health and flight safety issue by dominant industry stakeholders continues to be witnessed repeatedly. There is no longer any excuse, as the aviation and occupational health and safety legislation, while some could be enhanced, are quite clear as they stand and contaminated air is not acceptable and can no longer said to be rare, affecting a small minority only or adequately addressed.

With this depth of knowledge and evidence available, the aviation industry and its partners can only be accused of wilful misconduct or grand incompetence. However, for the major stakeholders, the former is the case as the evidence and manipulation of data is too strong. For those who say otherwise, (including some crew unions) they are demonstrating a clear lack of having suitably reviewed the evidence or are enabling the current industry practices to continue. Likewise, those who have suggested there is a need for more data to be gathered before action can occur, they too would be demonstrating an industry aligned corporate bias or a lack of having reviewed the material and proof that they have accepted the industry positions, even if unwittingly.

It has been stated that *'Perhaps no industry has employed the strategy of promoting doubt and uncertainty more effectively for a longer period than has the tobacco industry.'* [10] The aviation industry in continuing misuse of the available evidence for well over 50 years is fast rivalling this example. The strategy of manufacturing uncertainty is antithetical to the public health principle that decisions be made using the best evidence available. [10] However, the strongly allied partners within the aviation industry have a product to protect and have therefore ignored for some time the evidence that has not suited them and have been attempting to create their own.

The aviation industry and its alliances have now joined forces to create inconclusive findings and therefore provide the "research" that it requires to manage the situation and acquire the answers it needs. This is done ultimately to not only protect the product but with some intending to profit from selected solutions that are now being developed by key players at the expense of also addressing the human cost. Individuals or corporations trying to simply understand this issue for the benefit of health and safety have had little chance against this systemic industry malpractice that has focussed on creating disease and disability (by ignoring the source of the problem) rather than introducing safer engines and systems. This will continue to be the case until those who are genuinely concerned accept that the evidence available, show it is more likely than not that there is a cause and effect and consequently demand the problem be addressed. This is the case and over 60 years later it is time for real solutions.

It is often suggested that the only thing that will lead to industry change is economic pain, to date this has not led to solutions that are required. While there is a vast amount of media attention, [11] questions raised in Parliament (often with inaccurate answers provided) [12] and a number of legal cases, none to date have brought resolution to the issue. Of course limited actions have been taken in part due such pressures, with one example being the design of the Boeing 787 without bleed air, however the core problems remain. The industry has a dominant hold and has ensured the media remains confused, inaccuracies are provided in parliamentary responses, the public remains relatively unaware and the deepest pockets rule the courts.

There are a number of examples now available where positive action has been taken based on good science and common sense. The Australian F111 Reseal/Deseal program and Gulf War Illness provide clear evidence that a cause and effect can be established where there is a will to do so and the term syndrome is immaterial as it is the detail that counts.

However, a number of issues are faced for which the industry has been put on notice. These include the crew and passengers legal right to know and determine risks; the carrier owes a duty of care not to cause harm or injury to others whether they be crew, passengers or the unborn; the question of wilful blindness versus recklessness; and appropriate precautions taken with measures adopted such that if taken by an airline, it *'need not be concerned about being found guilty of reprehensible conduct.'* [13] The evidence provided in this thesis goes some way to clearly show the industry has failed to meet these obligations and therefore such a term *'reprehensible conduct'* is fully justified.

With this body of evidence, it is hoped that the industry can move forward and provide aircrew and passengers a safe workplace, mode of transport and appropriate and healthy (bleed air or non bleed air) environment in which to undertake these activities. Actions and appropriately designed research are without doubt urgently warranted.

9.2 Recommendations

While the 1999-2000 Australian Senate Inquiry listed a number of the suggested actions and recommendations below, they were essentially all ignored by the Australian Government. [14,15] However many are repeated here ten years later.

9.2.1 Urgently required actions

Based on the evidence throughout this thesis a variety of recommendations are made, broken down into research and actions.

9.2.1.1 RESEARCH

- Synthetic jet engine oils and other fluids should be assessed for overall toxicity of combined pyrolised by-products rather than individual chemicals in a manner in which exposures mostly occur, that is via inhalation. Research should also focus on specific areas such as TCP and other TAP biomarkers and polyol ester based synthetic oils should be assessed for toxic by-products creation such as TMPP, inhalation toxicity of other TCP and TAP isomers (non ortho) and similar;
- Research into thermal degradation and pyrolysis of the ester base stocks is required in relation to inhalation exposure;
- Establish standards and control measures for all contaminants suitable for the cabin air environment and the heated mixture of contaminants, rather than individual ground based standards;
- Exposure limits should be re-evalauted to provide protection to the most vulnerable sub groups that include the young, the infirm, the unborn, the pregnant and those who may be genetically more at risk from potential exposure effects etc.;
- Establish suitable biomonitoring and other techniques able to identify exposure to contaminated bleed air;
- Better designed engine and APU oil seals and bleed air systems that do not allow oil to leak;

- Development and introduction of effective bleed air filtration or bleed air cleaning systems should be introduced on current non ‘bleed free’ aircraft;
- Installation of effective bleed air detection (real time monitoring) systems identifying suitable markers to detect contaminated air should be introduced in each bleed supply line. This will alert crews when contamination is occurring and aid engineering with subsequent fault diagnosis;
- Research should be undertaken into the health effects associated with contaminated bleed air using case control studies and expertise free of industry/Government alliances.

9.2.1.2 ACTIONS

- Currently used TCP additives should not be used as a substance in synthetic oils in engines that use ‘bleed air’. Use of less toxic oils and fluids should be developed, mandated and introduced;
- Information on jet oils should be revised to accurately advise users of the true nature of hazards to exposure to jet oil and fluid mists, fumes and vapours and how these hazards can be controlled and prevented;
- Appropriate engineering practices should be introduced to ensure leaks are addressed in a manner that ensures further contamination cannot occur when reported. MELs should not be applied where downstream contamination will have occurred;
- As clean air is an airworthiness issue, ongoing defects addressed through service bulletins should be made compulsory by way of airworthiness directives or alternatives;
- Clean air under FAR/CS (EASA) 25.831 ‘a’ and ‘b’ must be immediately regarded as part of the ongoing aircraft certification requirements as was originally intended. This must address all contaminants using standards suitable for the cabin air environment and the heated mixture of contaminants, rather than individual ground based standards;

- All suspected contaminated air events must be reported as an aircraft defect to the regulators and be made available to crew and the public. The appropriate aviation legislation must then be adhered to and enforced;
- The industry should stop trying to rationalize the extent of the contaminated air problem in terms of the number of bleed air reports as the reporting system is not working;
- Crews must use oxygen whenever contaminated air is suspected and passengers should be provided protection from such exposures;
- Education for the entire industry that exposure to contaminated bleed air is a flight safety hazard and health issue;
- Organizations within the airline industry must accept their OH&S responsibilities under the existing legislation with clearly identifiable appropriate systems to ensure the legislation is met;
- Risk assessments must be inclusive of workers and passengers rather than excluding such vital data;
- Aviation regulators and OH&S regulators must both use their expertise to address the bleed air issue and must not defer responsibility to the other without suitable expertise;
- Workers who report adverse effects from bleed air should be appropriately investigated;
- Individuals who have been exposed as crew or as passengers should be made aware of this fact. Details of the chemicals they have been exposed to should be provided to them so as to enable their physician to be able to treat and monitor their health appropriately;
- Health systems should be developed to identify and treat people exposed to contaminated bleed air and exposed individuals should be treated with respect;
- International utilization of the FAA funded OHRCA medical protocol should be introduced while further research takes place;

- Establishment of an international database for reporting adverse effects of exposure and assisting with international research to better understand the diversity of illnesses associated with contaminated bleed air; *‘Aerotoxic Syndrome’*;
- Establishment of an international database to record contaminated air events to assist with international understanding of the issue and required actions;
- Better systems should be identified to monitor, detect, diagnose, treat and compensate affected workers; Those affected to date require industry level compensation, rather than individual legal actions that fall prey to the issues identified in this thesis;
- All future aircraft should be designed as ‘bleed free’ as is the case with the Boeing 787 Dreamliner.

9.2.2 Reference

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10 Appendices

Appendix 1:

Incidents on the UK contaminated air database as of 1 August 2006

Appendix 1: Incidents on the UK contaminated air database as of 1 August 2006

DATE	TYPE	CAA REF NO	DETAILS OF INCIDENT
1-May-1985	BAe 146	198501251	Hydraulic Fumes in cabin / SB 21-24-00543A/B (CLASSIFICATION MANDATORY) Airworthiness Directive Sept-1985: Improve the sealing of the hyd bay to prevent Fumes entering the cabin
13-Jun-1985	BAe 146	198501879	Hydraulic leak. Pax coughing / Mandatory SB SB 21-24-00543A/B: Improve the sealing of the hyd bay to prevent Fumes entering the cabin
28-Jun-1987	BAe 146	198701543	Number 2 bearing seal failure / Dan Air
26-Mar-1988	B757	198800875	Strong smell of electrical burning on f/deck / recirc fan blocked / warm oily smell
4-Oct-1988	B757	198804246	Smell of burning on flight deck / priority landing
9-Feb-1989	BAe 146	198900370	Oil leak in APU caused Fumes in cabin / SIL 21/7 & 21/54 / Dan Air / Manufacturer has issued info on suitable action to prevent this problem SIL 21/7 & 21/54 ref.standard procs & fm drills considered satis to control this problem.
18-Jun-1989	B757	198902234	Oily smell in f/deck & cabin
31-Jul-1989	BAe ATP	198902945	HP pressure turbine failed & oil pressure loss / Initially not on CAA database- refer MOR 199802989
14-Mar-1990	BAe ATP	199001065	Prop barrel bore & prop blade bearing inner races corroded - Found on C check investigation of oil leak / Initially not on CAA database until further request made - refer MOR 199103755
22-Jul-1990	BAe 146	199003460	Fumes inside aircraft / Pax & crew irritation. Hydraulic leak / CAA / BAe service difficulty report 21/7 refers
30-Dec-1990	BAe ATP	199005598	Smoke warn during climb - Fumes inside a/c. returned / oil leaked into air condn sys from number 1 eng pressure valve.
23-May-1991	BAe 146	199101548	Smoke on flightdeck due overheat of air conditioning packs / previous temp control problems though no tech log entry made / manufacturer suggested oil was reason for smoke on flight deck
17-Jun-1991	BAe 146	199101992	Oily smoke on flight deck
29-Aug-1991	BAe ATP	199103135	Acrid smoke in passenger cabin. emergency call, a/c returned / environmental control system (ECS) packs operated & no further smoke detected / CAA closure: smoke considered to have resulted from light oil contamination of the heat exchanger matrix in the air conditioning system during maintenance
28-Sep-1991	BAe 146	199103648	Pax & crew suffered nausea- headaches / APU blowing oil / Dan Air
30-Sep-1991	BAe ATP	199103755	CWP smoke warning - smoke / Fumes in cabin. a/c returned. Possibly due to heavy oil leak from number 2 engine propeller barrel / blades. Considerable oil ingress to air intake. see also 90/01065.
15-Nov-1991	BAe ATP	199104314	Smoke inside a/c after number 2 ECS pack selected on. a/c shutdown & evacuated. Number 2 intercompressor case drain plug contaminated with oil.
23-Nov-1991	BAe ATP	199104450	Smoke in cabin. a/c returned. air conditioning system contaminated with oil leaking from nr3 blade of nr1 propeller / oil entered through air intake / AFS / propeller seals found to be leaking - seals replaced, oil replenished & subsequent engine ground runs satisfactory. CAA closure: mfr issued sil 61/2 highlighting this problem - a training video on seal replacement also available.
2-Mar-1992	B747	199202198	Oil mist / smoke in cabin from nr1 air conditioning pack. Number 1 engine oil contents reduced to 3 gallons / NFF

Appendix 1: Incidents on the UK contaminated air database as of 1 August 2006

2-Apr-1992	BAe ATP	199201561	Oily smoke inside a/c (with associated warning) when nr1 air conditioning pack brought on line / Return to stand / ACM oil contents very low
28-Jul-1992	BAe 146	199203107	Smoke on flight deck / Number 9 bearing seal failure
31-Aug-1992	B757	199203577	Smoke on flight deck & in cabin, nr1 engine oil pressure/quantity low. Engine shut down, a/c diverted / Primary cause of failure attributed to steady bearing failure
20-Nov-1992	B737	199204832	Fumes / smoke from air conditioning system - suspect due to recent r/w de-icing treatment (allegedly not advised to crew) / AFS
30-Nov-1992	BAe ATP	199205353	Smell of hot oil on flight deck followed by smoke 'CWP' warning. Suspect contamination of nr1 air conditioning pack / NFF
2-May-1993	B747	199301470	Cabin filled with smoke as a/c taxied to stand after landing. During subsequent emergency evacuation 8 pax were seriously injured / smoke caused by APU lubricant leaking into air conditioning system
9-Jan-1994	BAe ATP	199400181	Thick smoke in cabin after engine start & ECS pack 1 selected on. nr1 engine / pack shut down / ground run cleared contamination & system subsequently operated satisfactorily
12-Feb-1994	BAe 146	199405255	Cabin filled with smoke / Number 3 engine oil leak.
21-May-1994	B757	199401991	Smoke / Fumes on flight deck & in forward pax cabin / AFS / evacuation / Paper & plastic debris obstructing the primary heat exchanger matrix
2-Aug-1994	B757	199403588	Strong smell of electrical burning / priority landing / NFF
7-Apr-1996	F100		G-UKFF / AAIB bulletin 9/96 (G-JEAK report). All 4 cabin crew unwell / Emergency / 02 / P1 advised crew had ingested 'something abnormal' / no fault found /
10-Apr-1996	F100		G-UKFF / (G-JEAK report) / 2 cabin crew unwell with headaches / no fault found / could have been misuse of cleaning agent
22-May-1996	B757	199602149	Acrid blue smoke on f/deck & cabin
18-Jun-1996	B757	199602535	O2 Used
20-Jun-1996	B747	199602531	Smoke in cabin due nr4 engine bleed air contaminated with oil / fuel dumped / a/c returned.
11-Jul-1996	BAe 146	199602896	Smoke / Smell in cabin / Mayday / Fault not reproduced / Considered random occurrence
24-Jul-1996	B757	199603341	O2 Used
18-Aug-1996	BAe 146	199603622	Oily smoke / Fumes in pax cabin / Number 3 engine oil contents low / Oil seal leak found.
31-Oct-1996	BAe 146	199604940	Recurring fault / flight crew felt nauseous / eye irritation / 02 / diversion
4-Jan-1997	BAe 146	199700054	Cabin filled with oily smoke / ADD already raised / suspect number 2 bearing / seal failure
4-Jan-1997	BAe 146		Same problem (same day) as MOR 199700054- refer MOR 199700054
14-Jan-1997	B757	199700433	During third sector P1 & P2 experienced burning of eyes & throats.
27-Jan-1997	B757	199700623	Air conditioning duct pressure fluctuating. Smoke became evident in flight deck & pax cabin.
19-Feb-1997	B757	199701165	Burning smell & haze evident throughout a/c. Pax disembarked. Suspect exhaust fumes ingested into air conditioning system.
9-Mar-1997	BAe 146	199701150	Fumes evident in pax cabin

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29-Jun-1997	B737	199703564	Strong burning smell evident from upper rear cabin - suspect air conditioning packs contaminated with oil / hyd fluid.
9-Sep-1997	BAe ATP		ASR / G-BTPE / BA1880 / MAN-ABZ / Fumes described by P1 as worst ever experienced / Company report stated: " Engineering investigation by boroscope revealed an oil leak within the engine core, as a result an engine change was ordered and the defective engine sent for overhaul. The overhaul findings revealed that three of the High Pressure (HP) turbine blades had failed. This in turn had caused the Hp turbine disc to become out of balance and therefore cause vibration throughout the engine. As a direct result of the vibration the engine seals were damaged allowing the oil flow path, this allowed the oil to be heated creating the smoke which found its way into the air conditioning supply path."
20-Oct-1997	BAe 146	199705583	Pax cabin filled with smoke upon APU air selection. Pack burn
4-Nov-1997	B757	199705805	Very strong pungent oily smell in flight deck up to approx 8000ft, after which only a mild smell was noticed. Oily smell again very strong on flight deck during next departure but mild in cruise - during latter part of cruise both flight crew experienced sore eyes/throats & mild headaches. Subsequent medical examination confirmed that both flight crew members had been exposed to toxic Fumes which had caused minor burn damage to their eyes. / Opr/engine mfr invstgn concluded incident due to easing of engine compressor flange bolt, due excessive application of dry film lubricant, allowing small quantities of engine oil into a/c systems.
13-Nov-1997	A320	199706031	Acrid smell evident for three sectors / cabin crew in aft cabin also reported Fumes & felt nauseous & eye irritation / inspection of the APU found the intake to be oily and dirty / APU changed / strip down investigation found APU carbon compressor "c" seals deteriorated. improved seals are the subject of SIB 49-7287
24-Nov-1997	BAe 146	199706864	Strong smell of fumes causing severe crew discomfort. Number 1 bearing seal / diversion / 02 / Fumes became progressively worse during the cruise with all of the crew experiencing strong stinging of the eyes and nose - dryness to the throat - headache and breathing problems.
3-Dec-1997	BAe 146	199706292	Smell of burning in cabin / number 3 engine oil filler cap found leaking oil.
4-Jan-1998	B757	199800072	Smoke evident in cabin & flight deck while electrical power was being supplied by ground power & air conditioning from APU / NFF
6-Apr-1998	DC10	199801726	On ground large amount of smoke from APU entered cabin / oil then noticed leaking from APU / APU placarded inoperative & MEL raised. Pack burn for duration of turnaround with no visible smoke in cabin / on taxi out smoke in cabin again / a/c returned to stand & engines run for 1 hour & air conditioning packs exercised through full range to purge system / flight resumed but cabin again filled with smoke & smoke alarms activated when air conditioning was introduced early in climb / fuel dumped & a/c returned with P2 using oxygen as a precaution / high power ground runs carried out on all 3 engines - packs run at full heat then cold several times until all evidence of oil smoke cleared. All ducts purged of oil residue after 1 hour. a/c then considered serviceable.
28-Apr-1998	B757	199802188	P2 felt nauseous & member of cabin crew experienced eye irritation.
3-May-1998	B737	199802381	Cabin filled with acrid Fumes / pax disembarked / unidentified fluid in air conditioning distribution bay / source of fluid was not determined.
1-Jun-1998	BAe ATP	199802989	Smoke in cabin in climb / a/c returned / rh engine oil leak due lp turbine blade failure which contaminated air conditioning system / see also 89/02945, 94/05304 and 95/00225 (none available for review initially until further request made)

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4-Jul-1998	B737	199804263	Smoke haze / oily smell at rear of cabin / pax evacuated / operator investigation found incident due to maint error causing pack overheat.
1-Sep-1998	B757		ASR / D. Hopkinson (no longer able to hold medical licence) / Toxic Fumes on the f/deck. MOR box selected by Captain but report was not sent to the CAA by the airline until issue raised at Governmental level
5-Oct-1998	Concorde		G-BOAD / BA2 / Smoke warning from no.3 air group with No. 1 air group shut down due smell. "This is a common minor fault."
15-Oct-1998	Concorde		G-BOAG / BA3 / Air con smoke warning / Contamination isolated to No. 2 air group
20-Dec-1998	BAe 146	199807327	Flight crew (and one pax) suffered stinging / watering eyes & stinging in nostrils. De-icing?
8-Jan-1999	BAe 146	199900061	Strong Fumes - recurring fault / no fault found / Suspected exhaust fumes / fuel
14-Jan-1999	B757	199901967	Strong smell of noxious Fumes on flight deck throughout flight. P1 & P2 felt nauseous & developed headaches / NFF but reporter suspected oil fumes
15-Jan-1999	BAe 146	199900160	Smoke. De-icing ? / Return & emergency evacuation / French investigation
21-Jan-1999	BAe 146	199900440	Flight deck crew incapacitation / 02 / Manufacturer suggests dry ice / P2 reported blurred vision, tingling in fingertips & a lack of concentration - face was white with lips discoloured & pupils dilated / P1 assumes control / P1 felt light-headed with tingling in fingertips.
24-Jan-1999	B747		G-BDXC / Fumes & smoke during de-icing / possible leak in APU
30-Jan-1999	BAe 146	199900500	Smoke & Fumes / O2 / de-icing ?
8-Feb-1999	B757	199900790	Fumes / blue smoke on flight deck & pax cabin / Air conditioning contaminated by de-icing fluid applied before departure
22-Feb-1999	BAe 146	199900890	Burning smell / No fault found / PAN
23-Feb-1999	BAe 146	199901084	Fumes / De-icing ? / Known fault / uncomfortable.
9-Apr-1999	BAe 146	199902171	Smoke inside a/c with associated warnings. "Pan" declared. A/c returned. Ingestion of de-icing fluid suspected.
9-Apr-1999	BAe 146	199902108	Oily smell in cabin / APU contaminated with oil. 2 cabin crew / Nausea & pupils dilated / 02 / see 199900440 / See Digest 99 / D/06
15-Apr-1999	BAe 146	199902171	Smoke / De-icing ? / PAN
20-Apr-1999	B737	199902384	Cabin filled with smoke during APU start/air changeover. APU seized.
23-Apr-1999	BAe 146	200002798	Smoke in cabin
26-May-1999	BAe ATP	199903247	Smoke & fumes inside a/c during engine start / SILs 71/11 and 71/014 address subject of trouble shooting smoke/oil mist in cabin on start
18-Jun-1999	B737	199903880	G-MSKB / initially not on CAA database / Same problerms as other MORs but in this case suggest dirty ovens - refer MOR 199905268 - same aircraft
7-Aug-1999	B737	199905268	G-MSKB / acrid burning smell & smoke in cabin / PAN / emergency evacuation / incorrect installation of a seal may have been the cause but positive cause could no be established / overhaul organisation suggested that this may have only been a problem during transients - see also 99/03880 and 99/06967 (same a/c) / not available for review initially
8-Aug-1999	B777		BA069 / smoke haze in cabin & f/deck / 02 / PAN / cabin crew had acrid taste in mouths

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17-Aug-1999	BAe 146		BAe 146-300 / G-BTTP / GLA to STN - pax feeling nauseous - PAN - O2 Used
28-Aug-1999	B757	199906129	Unidentified loud bang & toxic smoke inside a/c. "Mayday" declared. Diversion / no fault found
30-Sep-1999	B737	199906967	G-MKSB / Both flight & cabin crew complained of dizziness & feeling light-headed throughout flight / unable to ascertain cause / fresh air helped then operated next sector on different a/c / investigation under MOR 199905268
6-Oct-1999	B757	199906912	G-BPED / PAN / Divert to Paris / O2 / Crew had difficulty explaining urgency to ATC / oil leaks found / AAIB
30-Oct-1999	BAe 146	199907477	Fumes / Flight crew, cabin crew and some pax felt light headed / 02 / PAN
12-Nov-1999	BAe 146	199907922	Fumes / Both flight crew partial incapacitation as well as cabin crew unwell / recurred over several flts / O2 / Swedish Investigation; Both pilots unwell / P1 continued to feel sick (dizzy groggy) despite 02 / P2 feeling better / P1 slowly recovered after approx 2 minutes / On previous flights both flight crew & cabin crew felt unwell with unusual smell / odour evident.
13-Nov-1999	B757		G-BMRG / Strong smell of fumes with tech log entry regarding from a previous flight / P1 & P2 aware of headaches, a strange feeling of being affected by the fumes and P2 could taste & feel in throat / P2 experienced drop in health just weeks after going on 757 and improvement after leaving fleet / ASR but generally not recorded on previous& post flights with fumes except occasional tech log entry.
29-Nov-1999	B757	199908241	Flight crew reported cumulative physical symptoms. Similar defect reported for this a/c in June
20-Dec-1999	B757	199908757	P1 felt dizzy / light headed / both flight crew donned oxygen masks
20-Jan-2000	B747	200000328	Hydraulic system fluid loss & hydraulic Fumes in cabin
24-Jan-2000	B757	200000380	O2 USED
19-Feb-2000	B757		G-BMRF / LHR-VIE / BA 0700. Strong oil smell in flight deck air conditioning system after engine start.
17-Apr-2000	BAe 146	200002623	ASR / Transient smoke / Fumes on flight deck
25-May-2000	B757	200003702	Smoke in flight deck before passenger boarding / cabin crew evacuated / AFS / Air conditioning run for I hour with NFF / released for service
1-Jun-2000	B757		G-BIKC / Notes refer AAIB JEAK report on incident 25/1/01 / Both flt crew with nausea - acute stomach pain - headaches; No ASR filed / no medical attention sought
4-Jun-2000	B757		G-BIKV / Fumes throughout flight / Tunnel vision - disorientation - dizziness on arrival / Engineering reported long history of fumes / Crew declared sick on arrival & positioned back to LHR as no med facilities available / aviation medical dept.
19-Jun-2000	B737	200004269	Cabin crew in rear galley felt light-headed and uneasy on their feet. Eyesight affected, pressure felt behind the eyes / Initially not on CAA database- refer MOR 200004394 / G-MSKB - master occurrence / See also 1999/03880, 1999/05268, 1999/06967, 2000/04394 and 2000/05325 - all similar problems on same a/c / An extensive investigation that included the use an air sample canister was carried out by the operator but no positive conclusions as to the reasons for complaint by the cabin crew were made
21-Jun-2000	B737		G-MSKB / reports of cabin crew feeling unwell with similar reports & MEL in incident 2 days later- same aircraft / refer MOR 200004394
22-Jun-2000	F100		G-UKFN / AAIB (G-JEAK) / all cabin crew light headed & nauseous in crz/descent / portable 02 used
22-Jun-2000	F100		G-UKFN / AAIB (G-JEAK) / all cabin crew unwell in climb / crz / Unable to do rt sector due headaches/nausea

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22-Jun-2000	B757	200004381	Smoke in flight deck and cabin after a/c shutdown / wear to the load compressor (LC) carbon seals.
23-Jun-2000	B737	200004394	G-MSKB / AAIB / All 4 cabin crew nauseous- light headed & hot after ldg / aircraft had history of such problems -recurring / similar report 2 days later -"reporter confirms that a/c has an open add regarding air quality with previous reports of cabin crew feeling unwell" / similar symptoms reported by different crew during flight 2 days later / air sample taken & sent for analysis
25-Jun-2000	B737		G-MSKB / similar symptoms reported by different crew to incident 2 & 4 days previous- refer MOR 200004394
11-Jul-2000	BAe 146	200005129	MOR / G-JEBC / Not on initial data review of CAA Database / P1 felt unwell / experienced headache after operating four sectors. Alleged recurring problem on this a/c / P1 recovered by next day (12 Jul 2000) but symptoms returned after operating another four sectors on same a/c. Discussion with morning crew revealed that they had experienced similar symptoms. P1 had experienced similar symptoms in April, consultation with log book identified that P1 had been flying this particular a/c on these occasions as well
12-Jul-2000	BAe 146		G-JEBC / See MOR 200005129 / day before / P1-symptoms returned after operating another four sectors on same a/c. Discussion with morning crew revealed that they had experienced similar symptoms.
12-Jul-2000	BAe 146		G-JEBC / See MOR 200005129 / day before / Discussion with morning crew revealed that they had experienced similar symptoms as P1 day before & later that day - same aircraft
12-Jul-2000	BAe 146		Similar smell on flight deck as on next day (MOR 200005167) but no adverse effects on crew / pax. No fault found
13-Jul-2000	BAe 146	200005167	Intermittent electrical burning smell / Cabin crew felt unwell throughout flight / Symptoms incl feeling dizzy and disorientated, tiredness and headaches (including pain behind the ear). Approximately 30 passengers slept during flight which is unusual for a lunch-time sector / No fault found
13-Jul-2000	BAe 146	200005869	Refer MOR 200005167 / Symptoms recurred during return sector
17-Jul-2000	BAe 146		MOR / G-JEBC
36731	B737	200005325	G-MSKB / Rear cabin crew reported CO indicators changing colour (becoming darker) during cruise. No adverse effects on crew reported / prior to the sector a diesel powered GPU had been used because standby power was unavailable / All crew stood down on arrival. Investigation progressed under 2000/04269
17-Aug-2000	B737	200006248	Smoke haze in main cabin whilst a/c on stand. Precautionary evacuation. hydraulic fluid contamination suspected.
21-Aug-2000	B757		G-BMRE / Both crew and 1 cabin crew experienced nausea.
29-Aug-2000	BAe 146	200006413	Smoke. Refer 200002798 . Fire services / MOR - G-JEBC / CAA Ref: 200005129 / AAIB 2000/03/05
1-Sep-2000	BAe 146	200006659	Smoke is a known occurrence on this aircraft type - yet heaviest experienced. No fault found
5-Sep-2000	BAe 146		ASR / MOR - G-JEBC / CAA Ref: 200005129
12-Sep-2000	BAe 146		ASR / MOR - G-JEAV
20-Sep-2000	BAe 146		ASR / MOR - G-JEBC
21-Sep-2000	BAe 146		ASR / MOR - G-JEAV
22-Sep-2000	B747	200007054	AAIB AARF investigation: smoke on flight deck and in pax cabin. emergency declared. a/c returned / oil had entered the air conditioning bleed ducts from the nr 2 engine connected to previous bird strike damage

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15-Oct-2000	BAe 146		ASR / MOR - G-JEAJ - CAA REF: 200007650
15-Oct-2000	BAe 146	200007724	Fumes- PAN / 02 / G-JEBC / strong oil odour / misting in cabin / all crew on oxygen / diversion to BHX
25-Oct-2000	B757	200007913	O2 USED / Both felt light headed / On shut down / both pilots still felt light headed & also shaky.
2-Nov-2000	BAe 146		ASR / MOR - G-JEAM
2-Nov-2000	BAe 146	200008???	Air conditioning systems contaminated with oil. PAN / 02 / G-JEBC / ASR / MOR
5-Nov-2000	BAe 146	200008340	G-JEAK - Approach to Birmingham / P2 incapacitated and P1 seriously performance impaired / 02 / AAIB / Commander also felt "light headed" and had difficulty in judging height during the ensuing approach and landing. Research and tests suggests that the crew of G-JEAK and the crew of other aircraft which have suffered similar incidents - may have been exposed to turbine engine oil derived Fumes in the cabin/cockpit air supply - originating from either an engine or APU - which had irritant - rather than a toxic effect. Oil leak in APU.
7-Nov-2000	B757	200008363	G-CPEL / Oily smell on outbound sector / On return sector crew unaware that they were becoming partially incapacitated / P1 then forgot to slow a/c. AAIB / 'Oily metallic smell had also been evident during previous sector. On this occasion, numerous ATC calls were missed, prompting ATC to ask a/c if everything was all right. P1 then forgot to slow a/c during approach until reminded to do so at 3.7d. Crew unaware that they were becoming partially incapacitated.'
8-Nov-2000	BAe 146		Same aircraft as 5 Nov 2000. Serious incident according to CAA but not in CAA database. Refer AAIB report for 5/11/00) / acrid Fumes / no fault found / released for further flt / AAIB EW/C2000/11/4
9-Nov-2000	BAe 146	200008834	G-JEBD / Both pilots experienced eye irritation - headaches / P1 dizzy & difficulty completing technical log / AAIB / Entire crew declared unfit for further flying duties
11-Nov-2000	BAe 146		Same aircraft as 5 Nov- 2000 Serious incident. Not in CAA database at all / AAIB EW/C2000/11/4
11-Nov-2000	B757		Event referred to in CAA Ref 200008363
13-Nov-2000	BAe 146		Same aircraft as 5 Nov 2000. Serious incident. Not in CAA database at all (refer AAIB report for 5/11/00) / Fumes traced to APU / AAIB EW/C2000/11/4

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23-Nov-2000	BAe 146	200008697	G-JEAM - Fumes- P1 had great difficulty concentrating / 02 / Fumes had been ongoing since mid oct- 1999 (AAIB) / strong fumes on outbound sector & repeat on rt sector. P1- difficulty completing fuel check & R/T tasks & concentrating- headache- dry throat- irritated eyes & aware not OK.. other cabin crew members also effected similarly. P1 on 02 / P1 later developed blisters inside mouth/tight chest- sore throat & coughing / Same p1 as in 9/11/00 incident. Fumes traced to no. 3 engine. unusually high proportion of the passengers (40-60%) were asleep. CAA Pretitle : Fumes in flight deck and cabin. CAA Precis : Prior to departure, both air conditioning packs had been changed and an ADD posted "Do not use APU unless in emergency". At 3000ft, as engine air 1 and 2 and pack 1 were selected 'ON', there was a strong smell of fumes in the flight deck for approximately 60 seconds. Five minutes later, fumes were reported in the cabin for a short duration but not long enough to carry out an isolation procedure. The remainder of the flight was uneventful. On the return flight, there was again a strong smell of fumes on the flight deck for approximately 60 seconds when the pack was selected 'ON' at 3000ft. During the later stage of the cruise, P1 found great difficulty in concentrating, had a dry throat, irritation of the eyes and a headache. The same symptoms were also reported by cabin crew. P2 said he smelt the fumes after take-off but was OK. P1 elected to don oxygen mask, but P2 declined. The remainder of the flight was uneventful. The entire crew were sent to hospital for blood tests, but no symptoms or problems were found. Discussion between P1 and nr1cabin crew, revealed that on both sectors the cabin crew thought that an unusually high proportion of the passengers (40-50% on the first sector, 50-60% on the second sector) were asleep, but there were no complaints of fumes or smells. The aircraft has been withdrawn from service and ferried to the operator's main maintenance base. CAA Closure: Investigation progressed under 200008340 - see AAIB AAR 1/2004.
27-Nov-2000	BAe 146	200008801	Smoke- Fire services.
6-Dec-2000	B757	200009253	Oil/burning smell and smoke/haze present in cabin prior to push-back. Suspect oil contamination in air conditioning system, possible APU oil seal fault / APU oil seal had been replaced two months previously, suspect component failed again / Initially not on 2005 CAA database / refer MOR 200305082
14-Dec-2000	BAe 146	200009228	Smell. Source unidentified.
23-Dec-2000	B757		G-BIKC / Event referred to in CAA Ref 200100510 / refer JEAK AAIB report on 25/1/01 incident
30-Dec-2000	BAe 146	200009406	Smoke / PAN.
1-Jan-2001	BAe 146	200100295	Not listed as incident in any reviews by CAA. Refer 200101818 (not in 2004 review / Referenced MOR only
9-Jan-2001	B757	200100389	G-BPEF / smoke haze - fumes in cabin on boarding- Pax disembarked. No fault found
15-Jan-2001	A320	200100225	Burning electrical smell in galley / PAN
19-Jan-2001	B757		G-BMRB / NO ASR /crew effects by both pilots
2-Feb-2001	BAe 146		

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20-Jan-2001	B757		G-BIKC / Both crew felt nauseous & had headaches / BAHS (British Airways Health Services) advised - refer JEAK AAIB report on 25/1/01/ no ASR
21-Jan-2001	EMB145	200100608	Mayday due smoke in f/deck / poss de-icing fluid?
25-Jan-2001	B757	200100510	G-BIKC / Aircraft declared tech due toxic fumes on f/deck on previous few sectors. Tech log: intermittent oil leak suspected. Defect cleared after fumes reported on 1st sector with a request to report further / ongoing history of oil fumes
26-Jan-2001	BAe 146	200101217	Smoke / fumes in cabin. No Tech Log entry made - unable to investigate. CAA Closure: No further action possible.
30-Jan-2001	BAe 146	200100625	Smoke / Emergency landing. Swiss investigation.
1-Feb-2001	BAe 146		G-BZAY / BA 8036 / fumes
2-Feb-2001	BAe 146		G-BZAU / BA 8039 / fumes /stinging eyes
4-Feb-2001	BAe 146		MAN-ZHR / FO unwell due fumes & handed over to Capt. Capt unwell with nausea on taxi in. BAe advised toilet fumes
8-Feb-2001	BAe 146		G-BXAR / BA 8131 / strong oil fumes
8-Feb-2001	B757	200100984	G-BMRF / O2 / Crew felt dizzy and made their eyes water. AAIB EW/G2001/02/17/ BAHS (British Airways Health Services) advice was that there were no short or long term medical implications.
9-Feb-2001	EMB145	200101025	APU smoke on flight deck/ cabin
10-Feb-2001	B757		ASR / G-BMRF / P1 & P2 Effects: Nausea - stinging eyes & sore throat. Long history of fumes. Aircraft returned under MEL. Both pilots have concerns over LT effects of inhalation of toxic & carcinogenic oil fumes. / AAIB EW/G2001/02/17
12-Feb-2001	BAe 146		G-BZAX / BA 8038 / fumes
15-Feb-2001	EMB145	200101030	Electrical burning smell on flight deck after shut down
16-Feb-2001	BAe 146		G-BZAY BA 8160 / fumes
19-Feb-2001	B757	200101139	G-BIKT / AAIB EW/G2001/02/17 / Suspected residual oil contam from previous APU leak / APU bleed air duct ruptured / emergency evac: P1 often smelt fumes & generally not recorded prior to this date & mostly not ASR'd as considered transient
19-Feb-2001	B757		G-BMRF / strong oil smell / 'aircraft has a long history of this problem'
22-Feb-2001	B757		Event referred to in CAA Ref 200100984//AAIB EW/G2001/02/17/ Oil smells for entire flt/ nose & throat irritation to both pilots / Referred to MOR only
23-Feb-2001	BAe 146		G-BZAW / BA 8086 / fumes
23-Feb-2001	EMB145	200101470	Burnt oil smell
3-Mar-2001	BAe 146		G-BZAU / BA 8084 / fumes
4-Mar-2001	B757	200101402	Smell & haze / PAN
9-Mar-2001	BAe 146	200101609	Smoke in hydraulic bay.
9-Mar-2001	B757	200101653	G-BIKL / Metallic smell / Effects: Irritation to mouth & nasal passages- headaches. Heavy oil contam on pack o/flow valve and CRT displays / Registered event with medical / Refer AAIB report J-EAK

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12-Mar-2001	EMB145	200101645	Suspect APU contaminated with de-icing fluid / Mayday
12-Mar-2001	BAe 146	200101598	Smoke on flight deck during descent / approach. "Mayday"
13-Mar-2001	BAe 146	200101818	G-BZAY / BA 8087 / Fumes in cabin. Cabin crew / pax - dizzy / nauseous & headaches throughout flight. Recurring problem on this aircraft.
14-Mar-2001	EMB145	200101819	Mist in cabin
25-Mar-2001	B757		G-BIKC
26-Mar-2001	EMB145	20012039	
26-Mar-2001	B757		G-BIKT
26-Mar-2001	EMB145	200102039	Not on CAA data base intially & unknown till CAA volunteered on 14/10/05 search / Lavatory smoke warning with associated mist evident in cabin. Following extensive troubleshooting, both engines were replaced. No further reports / See also 200007690
28-Mar-2001	EMB145	200102112	White mist & oily burning smell in cabin / recurring fault
29-Mar-2001	B757		G-BIKL / BA 438 / Very strong smell of oil / "aircraft had a history of left pack problems'
29-Mar-2001	B757		G-BIKG / BA 1435 / Noticeable oily smell after t/off / "this is a growing problem on this fleet"
3-Apr-2001	B757	200102217	G-BMRF / BA1338 / Burning oil smell on t/off- climb /Reporter concerned about health implications of organo phosphates.
5-Apr-2001	B757	200102325	G-BMRB / BA568 / Strong oil smell in air to f/deck / "number of reports on this subject… on several diff a/c". F/crew nausea
5-Apr-2001	B757	200102325	G-BIKL / Flight crew both experienced nausea / engineer on f/deck to see how bad problem was.
7-Apr-2001	B757	200102454	G-BMRF / Both pilots experienced headaches & could taste oil in mouth / throat / history of fumes on flight deck
13-Apr-2001	B757	200102487	G-BIKG / P2 confirmed nausea and both pilots had throat/eye irritation due smell/taste of smoke/fumes-again on 4/501- 8/6/01
13-Apr-2001	B757	200102727	G-BIKG / Oil fumes on f/deck caused impairment to both crew. P1 Thick headed and unwell & P2 also dizzy & tingling / 02 / fault recurred 4/5/01 & 8/6/01/ oil contamination removal procedure carried out
15-Apr-2001	B757		G-BMRE
18-Apr-2001	BAe 146	200102582	G-JEAK / Engine vibration then smoke / Pan & Fire services / failed No 8 bearing / AAIB 2001/04/20
26-Apr-2001	B757	200102756	G-BMRD / Both flight crew suffered from effects of 'heavy oily fumes' / Both crew had metallic taste in mouth. P1 had tingling lips & headaches for days after / AAIB- EW/G2001/04/28 / No cause found
29-Apr-2001	BAe 146	200102764	Cabin crew incapacitation due suspected fumes from APU. All 3 light headed / drowsy
2-May-2001	B757	200102968	Fumes on f/deck / 02 used by P2 / PAN
4-May-2001	B757	200103076	G-BIKG / P1 unwell due oil mist (unable to fly approach - partial incapacitation but could follow commands) from air con. P2 developed intense headache after ldg (lasting 30 mins) & more frequent since / ASR / no med attention sought.
5-May-2001	EMB145	200102922	Smoke & smell on f/deck & cabin / AFS / No 2 distribution valve part seized
10-May-2001	B757	200103044	G-BMRB / O2 / Effects from oily smell/taste of oil - tingling on lips film on tongue & sore throat
16-May-2001	A320	200103217	Burning rubber smell / Mayday / APU load compressor contaminated with oil

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17-May-2001	A320	200103411	Mist in cabin / PAN / Oil leakage 40 hours after engine overhaul due to protruding metal overlooked during overhaul - prior issue highlighted by manufacturer
17-May-2001	EMB145	200103355	Smell of fuel in cabin intermittently through flight / no fault found
19-May-2001	B757	200103267	G-BIKT / O2 USED AAIB-EW/G2001/05/20 / PAN / crew effects / oil leakage from No. 1 engine
20-May-2001	B757	200103277	Oil fumes on f/deck in various stages of flt / both pilots had irritation to eyes - nose and throat / Engineers confirmed smell on ground / Both pilots felt after effects of toxic fumes/ recurring fault / -FSR submitted -G-BYAI
25-May-2001	BAe 146	200103520	
28-May-2001	B757	200103661	Oil fumes on f/deck in climb
3-Jun-2001	B757	200103786	ASR / G-BIKX / oily smell in cabin during climb
3-Jun-2001	BAe 146		Reference made in MOR 2001 03957- Hydraulic leak with fluid being heated in ECS
3-Jun-2001	BAe 146	200103957	Thick blue smoke. Residual Skydrol heated in ECS (previous sector) or APU oil contamination of air conditioning system suspected; See 2000/ 08340- 2000/ 08697-2000/ 08834-2001 / 02582
8-Jun-2001	B757	200103915	ASR / MOR / G-BIKG / oil smell on flight deck. Burning throats to both pilots / MEL already applied from 4/6/01
10-Jun-2001	BAe 146	200104071	Nausea - stinging eyes by all. Problem recurred over several months. Oil seal failure. ISB 21-150 carried out again.
11-Jun-2001	BAe 146	200104026	Mist evident in cabin. Cold temps / cleared
18-Jun-2001	BAe 146	200104104	Acrid / disinfectant type smell / 1 cabin crew nauseous, vomited, dizziness & sore throat / 02 / then incapacitated / P1 felt nauseous & light headed during taxi-in / After arrival - both P1 and member of cabin crew left the a/c and recovered sufficiently after approximately 1hr to operate return sector.
24-Jun-2001	EMB145		Reference made in MOR same day - 200104298 / smoke & odour
24-Jun-2001	EMB145	200104298	Hot odour & smoke in cabin / PAN aircraft returned / failed air cycle machine/ similar event earlier same day
2-Jul-2001	EMB145	200104648	Pack 2 overheat / burning smell in cabin / Aircraft operated under MEL as no spares / carbon seal leaking and oil contamination found in bleed air system
5-Jul-2001	EMB145		Reference made in MOR 200104648 3 days earlier: carbon seal failure causing oil to contaminate air supply
7-Jul-2001	BAe 146	200104931	Smell on numerous sectors - P1 felt effects of fumes; P1 felt increasingly unwell with headache - difficulty concentrating - slept for over 12 hours (which was unusual). Symptoms returned during 4 sectors flown in the same aircraft next day.
9-Jul-2001	B757	200104643	G-BMRD / BA572 / O2 / Diverted back to LHR / "this is an ongoing issue" / P1 could smell & taste oil then light headedness
10-Jul-2001	B757		G-CPEL / BA 1494 / Burning smell & hazy smoke on flight deck & cabin / "this is an ongoing issue"
14-Jul-2001	B757	200104832	
14-Jul-2001	B757	200104871	Severe turbulence / smoke, fumes / MAYDAY

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17-Jul-2001	B737	200104888	Strong acrid smell/fumes in cabin and on flight deck which affected flight crew (light-headedness with sore throat and mild headache) a/c returned / reporter comments that previous history suggested that smell/fumes would clear but they did not / investigation revealed that the no3 bearing was suspect with the abradable liners completely worn. This had allowed oil to leak into the ecs supply, contaminating that system and causing the smell
5-Aug-2001	BAe 146	200105383	Strong smell in cabin / hydraulic fluid contamination / crew felt ill effects / 02 / PAN / suspected oil leaks / incident probably not unique
5-Aug-2001	B757	200105502	Oil smell on f/deck & cabin / Reporter confirms previous history annotated in Tech Log and suggests a/c unfit for service
6-Aug-2001	B757	200105576	Strong smell of oil fumes on f/deck / IP compressor contaminated with oil/ O2 / PAN / see 30/8/01 report; engine changed
7-Aug-2001		200105478	O2 USED / The co-pilot used O2 / smell caused irritation to the eyes and throat.
12-Aug-2001	B757		BA FCR / G-BIKV / 3 Sectors same problem / headaches - throat & nasal discomfort
17-Aug-2001	B747	200105857	Smell of smoke from the air conditioning system in cabin / fumes & smoke ceased when recirc fan selected off / no fault found
18-Aug-2001	B757	200105892	Strong smell of fumes in f/deck after t/off / No fault or contamination found / Oily taste on the lips and gums followed by sore throats.
20-Aug-2001	BAe 146	200106246	2 cabin crew members reported being very tired, headaches & ear problems / extensive investigation failed to identify cause
23-Aug-2001	B737	200106211	All 5 crew members (pilots & cabin crew) reported feeling nauseous with headaches / part power egr carried out for 30mins at 80% power, but no smoke or fumes were evident and no headaches or nausea experienced.
29-Aug-2001	BAe 146	200106244	During 2 consecutive flights 2 cabin crew were light headed with one vomiting on approach / procedure in place to ensure medical tests available but no monitoring to see if checks actually taking place
30-Aug-2001	B757	200106547	G-BIKV / BA 815 / refers 6/8/01 / oil found behind spinner
3-Sep-2001	BAe ATP	200106103	Nr2 engine fire warning during take off - take off rejected / AFS / During braking all warnings ceased / no evidence of smoke or fire upon investigation / Initially not on CAA database- refer MOR 200106335 & 200106054
3-Sep-2001	BAe ATP	200106054	Smoke warning/indications in cockpit / Aircraft returned / Failure of the nr2 Air Cycle Machine turbine shaft bearing seal / Initially not on CAA database- refer MOR 200106335
4-Sep-2001	B757	200106302	G-BMRA / All crew sent to BAHS (British Airways Health Services) and advised not to fly for 24 hrs / (refer G-JEAK AAIB report) / P1 noticed strong oil smell - metallic taste - began to feel light headed, slightly euphoric & 'uncoordinated' - errors of judgement during taxi in - garbled speech. P1 & P2 not well enough to operate next sector. Oil on No1 & 2 spinners / 2 cabin crew felt similar feelings to pilots after visiting f/deck
5-Sep-2001	EMB145	200106297	Smoke & fumes / APU failed suddenly / APU turbine seized
5-Sep-2001	B757	200106194	G-BMRB / BA1446 / LHR - EDI / adverse reactions felt by some crew members after fumes & smoke haze in cabin / PAN / both pilots on 02 / ground staff & engineers noted smell which was identified as from the air con system - see also 28/5/01 & 10/5/01 - same aircraft

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8-Sep-2001	BAe ATP	200106335	Smoke warning during climb together with slight haze and oily smell in cabin / air-conditioning system contaminated with oil from air cycle machine (ACM)
11-Sep-2001	BAe 146	200106395	Pungent electrical burning smell in cabin / cabin crew felt ill effects / no fault found / Air quality monitoring found CO at 10 ppm / sweaty socks smell with APU on
16-Sep-2001	BAe 146		Reference made of tech log entry of acrid smell in fwd galley on t/off 7 ldg with APU on / refer MOR 200106395
17-Sep-2001	EMB145	200106608	Light hazy blue oily smoke in cabin & f/deck/ A/c returned / 4&5 bearing carbon seals leaking
22-Sep-2001	BAe 146	200107183	Smoke in cabin / duct high temp
25-Sep-2001	BAe 146	200106838	Smoke - ruptured seals in APU / Mel'd for 3 days. See previous ASR - Number 2 bearing seal leak.
4-Oct-2001	A321		G-MARA / MON26/27 / oily smell in flight deck / A/c had a prior history of oily smells / fumes at various stages of flight but increased to very strong in descent / both pilots felt nauseous on return sector, eye irritation & generally feeling unwell. Engineers advised oil is carcinogenic and may be a serious health hazard
7-Oct-2001	B757	200107020	Irritant oil smell / Diversion / Unable to find defect / cabin crew and the passengers in the last three rows of the cabin began to complain of eye irritation, tight chest and headaches / suspected cleaning fluid may have caused this (not enough info provided)
9-Oct-2001	BAe 146	200107105	Oily smell / smoke / haze on flight deck - cabin - 1 Cabin crew / pax effected. Disembarkation / APU oil overfilled / B defect to look for contamination in 50 hrs
12-Oct-2001	B757	200107232	Diversion due to persistent acrid smell in the cabin (possibly related to IFE but insufficient info provided)
12-Oct-2001	BAe 146	200107235	Oily smoke filled cabin during boarding / APU changed
17-Oct-2001	EMB145	200107241	Strong smell of fumes in cabin / no fault found. 'It is possible that the smell was due to residual oil in the air conditioning system'
27-Oct-2001	BAe 146	200107497	Hot oil odour & haze in cabin after APU started / "only reported finding was an oil spillage in the APU bay"
28-Oct-2001	BAe 146	200107473	Smell of smoke in cabin
30-Oct-2001	BAe 146	200107483	G-UKHP / Dense acrid smoke in cabin - Hydraulic leak. Mayday. Emergency evacuation. AAIB / Some pax appeared to be choking & vomiting - manuf considered it unlikely that hydraulic fluid could have entered air supply
6-Nov-2001	B757		G-BMRD / BA570 / fumes on s/up. Considered transient fault
12-Nov-2001	B757		(see next line) G-BIKR
12-Nov-2001	B757		G-BIKR / Notes: strong oily smell / 2 Crew had headaches - sore throat. Crew on previous sector also reported fumes had reported on previous sector with aircraft accepted for further flight & report / no fault found / problem recurred over next 2 days
14-Nov-2001	B757		G-CPER / Effects: incl: tingling tongue - sore chest - headache - short term memory loss - nausea / company aviation medical dept.
21-Nov-2001	BAe 146	200108067	Fumes on flight deck - P2 adversely affected / ADD raised and cleared / fumes recurred. Oil leak in APU but no evidence of contamination of ducts
22-Nov-2001	B757		G-BIKR / BA479 / oil fumes on descent / MEL applied

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24-Nov-2001	B757		G-BMRA
1-Dec-2001	B757		G-BIKR / Note: Noxious fumes on f/deck / oily smell irritated nose & throat / Britannia and United also have problem which is resolved by engine replacement
12-Dec-2001	B757		G-BMRH
13-Dec-2001	BAe 146	200108775	Smoke in the flight deck and cabin. APU compressor bearing break up / All smoke in cabin came from burnt oil
14-Dec-2001	B757		G-BMRA / Effects (nausea & headaches). All 5 cabin crew report feeling faint nr ToD / 3 pax & 1cc requested medication for headaches / History of problem & change of engine in 2 weeks / in interim inspection of heat exchangers
17-Dec-2001	B757		Fumes
19-Dec-2001	B757		G-CPEO / BA 440
20-Dec-2001	B757		G-BIKO / BA1385 / strong oil fumes in f/deck / crew had nausea & eye irritation
22-Dec-2001	B757	200108639	G-BIKY / BA948 / O2 USED / Metallic taste - strongest ever encountered by P2 / no fault found / MEL applied then pack reinstated pending further reports
22-Dec-2001	A320	200108579	Smell of burning & smoke haze during initial climb / clamp on air con trim valve missing
23-Dec-2001	B737	200108565	Acrid smoke on flight deck and in cabin after take-off / 02 / PAN / aircraft returned / de-icing fluid contamination suspected / all members of crew exhibited minor smoke inhalation symptoms i.e. dry throats and a feeling of nausea
27-Dec-2001	B737	200108733	Smoke and Fumes on flight deck and in pax cabin after take-off / de-icing fluid contamination suspected /
27-Dec-2001	B757		G-BPEC
28-Dec-2001	EMB145	200108663	Acrid Fumes in cabin / source not identified / headliner, air duct & lavatory light assemblies replaced under SB 145-25-0206
30-Dec-2001	B757		Fume event-G-BYAO
30-Dec-2001	B757	G-BYAO	Fume event-G-BYAO
1-Jan-2002	B737	200200001	Smoke in the cockpit. possible de-icing fluid contamination / PAN / return to dept port / AFS / packs run for 45 mins… / no recurrence
4-Jan-2002	BAe 146	200200047	Smoke on flight deck. MAYDAY / 02. De-icing fluid contamination suspected
4-Jan-2002	B757		Fume event-G-BYAO
4-Jan-2002	B757		Fume event-G-BYAO
4-Jan-2002	BAe 146	200200016	Smoke on flight deck. MAYDAY. De-icing fluid contamination suspected but not positively identified. AAIB - EW/G2002/01/07
5-Jan-2002	B757		G-BMRH
6-Jan-2002	B757		G-BPEK / ASR / LHR-GVA / BA0732 / Strong oil smell in initial climb / no fault found
7-Jan-2002	B757		Fume event - G-BYAD
8-Jan-2002	B757		Fume event - G-BYAK

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11-Jan-2002	B747	200200204	Acrid stinging / recirc fan fault ?
13-Jan-2002	BAe 146	200200183	Both pilots experienced symptoms / 02 / P1 took 1 hr to recover before return sector; Both pilots suffered dry mouths - headaches - nausea - tiredness - irritated throats / Amongst other defects APU had ingested plastic of some kind
13-Jan-2002	B757		G-BPEJ / BA1489 / ASR / Strong oily smell during initial climb up to 8000 feet which eventaully disappeared
14-Jan-2002	BAe 146		G-JEAV / CDG-NCL / BE3020. During cruise all 3 CC felt dizzy & tired. Pax and Flight Crew not affected.
14-Jan-2002	B757		G-CPET / ASR / BA0872 / LHR-SVO / Oily smell on t/off- climb / no fault found
18-Jan-2002	B757		G-BIKO / BA1435 / EDI-LHR / " …ongoing problem on this fleet re oily smells in the flight deck". Crew did not use 02 as advised by airline this meant declaring emergency and felt best not to do unless really violent effects from the smoke. & "used to bad smells on aircraft". P1 left with sticky throat & bad stomach which was considered regular on 757. P1 advised smelt perhaps 100 times on aircraft & part reason for leaving fleet.
21-Jan-2002	A320		ASR / G-BUSF / BA558 / LHR-FCO / 'Avionic Smoke' on approach ECAM with very slight smell of smoke noticed by flight crew. Afet landing warning disappeared as did smoke smell. No fault found
24-Jan-2002	EMB145	200200453	APU smell of fuel apparent / MEL raised to use APU for starts only / Cabin crew report some light headed ness but OK to continue
26-Jan-2002	B757		G-CPEM / ASR / BA1443 / EDI-LHR / "This is a frequent type of event on this fleet"
28-Jan-2002	B757	200200461	G-BMRH / The crew experienced feelings of nausea and donned oxygen masks. APU inop pre flight due fumes noticed again in climb / PAN / 02 / Return to LHR / AAIB-EW/8/132002/01/16- problem with APU & L engine. APU found to have a slight leakage on the load compressor front carbon seal.
29-Jan-2002	B757		Fume event G-BYAK
29-Jan-2002	B757	200200457	Engine failure / Smoke from the burning oil entered the cabin and flight deck / Build up of carbon in bore of oil feed pipe leading to oil starvation - Aeroshell 560
29-Jan-2002	B757		G-BIKT / fumes on 2 sectors: referred to on 30 Jan 2002 BA ASR
30-Jan-2002	B757		G-CPEL / BA677 / IST-LHR / ASR Fairly strong oily smell in flight deck for 10 minutes during cruise and 5 mins on aproach. Crew decided to go onto oxygen.
30-Jan-2002	B757		G-BIKT / BA1433 / EDI-LHR / ASR / Just after take off the flight crew noticed a strong oily smell which lasted approximately 1 minute. Engines found to be over filled with oil. Flight crew reported oil smells on previous two sectors.
30-Jan-2002	B757		G-BIKT / ASR / MOR / oil smell in f/deck. Noted on 2 previous sectors. Aircraft grounded pending further investigation
30-Jan-2002	B757	200200807	G-CPEL / O2 USED / oily smell in f/deck in crz- descent
1-Feb-2002	EMB145		Fumes / tech log entry made
4-Feb-2002	BAe 146		Fumes suspected from air conditioning system / referenced in MOR 200105383 5/8/01
7-Feb-2002	EMB145	200200856	Strong burning smell immediately after landing / recurring fault / no fault found with engineers asking crews to ' report further'- After several similar events SB raised to improve oil sealing on engines with definitive work package which has led to marked reduction in smoke / fume related incidents

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13-Feb-2002	BAe 146		G-JEAW / NCL-CDG. AF 3023. Cabin Crew operating in rear of A/C complained of giddiness.
18-Feb-2002	EMB145		Referenced in MOR 200200856 / same aircraft / rubber smell on descent
26-Feb-2002	B757	200200457	Engine failure / Smoke from the burning oil entered the cabin and flight deck / Build up of carbon in bore of oil feed pipe leading to oil starvation - Aeroshell 560 / G-BYAX
26-Feb-2002	BAe 146	200201246	G-JEAU / LHR-LYS / AF 3047. All 3 cabin Crew & several pax complained of feeling unwell - headaches, sore eyes & dizziness / several defects in air con & pressurisation system / Mandatory-YES.
1-Mar-2002	B757		Fume event- G-BYAX
1-Mar-2002	B757		Fume event- G-BYAX
2-Mar-2002	B757	200201421	During consecutive sectors felt gradual deterioration in their condition / 02 / Crew both felt light headed with a shortness of breath- coughing & unable to breathe normally - fumes suspected
3-Mar-2002	B757		Fume event- G-BYAX
4-Mar-2002	A319		G-EUOF / ASR / MOR / LHR-VIE return to LHR / BA 0700 / Oily toxic smell / no source found / smell to lesser degree on subsequent sectors / Inspection found hat the green hydraulic system had been overfilled.
10-Mar-2002	BAe 146		On approach - Cabin crew report heavy smell - smoke from A/C system at rear. On next sector P1- P2 & Cabin crew headache. No fault found. G-JEAU
14-Mar-2002	B757	200201636	Smoke / fumes in rear galley / MAYDAY - unable to trace source of smell / - G-BYAS
14-Mar-2002	BAe 146	200201724	Fumes suspected from air con system. Fire services
23-Mar-2002	B757		G-BIKY / BA 1477 / ASR / Oily smell in flight deck during takeoff and climb continued up until cruise altitude. Initial investigation found no fault with subsequent ASR (190/02/752 event). Found left engine fault and replaced
25-Mar-2002	B757	200201992	G-CPEO / BA0680 / ASR / LHR-IST / Strong oil smell on flight deck after engie start and left pack selected on. Lasted 4/5 minutes decreasing in intensity from very strong to faint. Cause was suspected oil contamination of pack whilst not in use
28-Mar-2002	A320	MAY BE INCIDENT	ASR / G-BUSD / BA910 / MOR / After take off strong burning smell reported by cabin crew at rear of aircraft. Oil smell was found to be number 2 engine which was replaced. PAN declared. Pax and cabin crew slightly unnerved.
28-Mar-2002	A320	200201927	Heavy smell of smoke in cabin / abradable lining loss from air/oil seal / MAY BE INCIDENT ABOVE
28-Mar-2002	B737	200201931	Repeated fuel fumes on flight deck in climb / PAN / 02 / NFF
29-Mar-2002	B757		Fume event- G-BYAP
3-Apr-2002	B757		G-BIKY- referenced in in 5 April 2002 incident as "2nd report in 3 days"
5-Apr-2002	BAe 146		Oily smell then blue/white smoke filling flt deck. No 1 Pack switched off. On Gnd. G-JEBD
5-Apr-2002	B757		G-CPEM / BA0307 / CDG-LHR / ASR / Smell was not strong but noticeable after take off. Left pack selected off & smell cleared.

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5-Apr-2002	B757	200202092	G-BIKY / BA0477 / BCN-LHR / -refer 3/4/02 / During full power take off…strong oil smell noticed during take off and climb by flight crew and cabin crew at doors 1. P2 donned oxygen mask after feeling light-headed. Reporter confirms aircraft has history of oily smells. It was established the left engine was the oil smell source and left engine was replaced.
11-Apr-2002	B757		G-BIKT / FRA-LHR / BA0909 / ASR & MOR / Full power take off with oily smell on flight deck for approximately 8 minutes. Whole fleet being monitored for this defect
13-Apr-2002	B757		G-BIKG / Effects included thick-headedness and nauseus.02 Masks donned.
17-Apr-2002	B757		Fume event- G-BYAN
19-Apr-2002	B757		Fume event- G-BYAN
19-Apr-2002	B757		Fume event- G-BYAN
19-Apr-2002	B757		G-CPEM
20-Apr-2002	B757		FCR / HEADACHES & Eye irritation / G-CPEM
22-Apr-2002	B757		Fume event- G-BYAO
23-Apr-2002	B757		Fume event- G-BYAO
25-Apr-2002	BAe 146		G-JEBD / BHX-CDG / AF 3005. Oily smell then blue/white smoke filling flt deck. No 1 Pack MEL'd off / APU suspected to be contaminating packs
26-Apr-2002	B757		Fume event- G-BYAO
26-Apr-2002	B757		Fume event- G-BYAO
28-Apr-2002	A320		ASR / MOR / PAN / oily smell / Rt to base / engine intakes contaminated with oil
30-Apr-2002	BAe 146	200202713	Mayday- Smoke in cockpit
2-May-2002	EMB145	200202802	Burning smell on f/deck during taxi out / P1 mildly unwell / No fault found / problem recurred 6/2/02
9-May-2002	B757		Fume event- G-BYAT
9-May-2002	B757		Fume event- G-BYAT
10-May-2002	B757		Fume event- G-BYAT
18-May-2002	A320	200203155	Two members of the cabin crew reported as feeling 'light-headed' and 'tingly' in the rear galley and purser felt 'strange' / PAN declared as 1 cabin crew member required medical assistance / all 3 cabin crew members affected were taken to hospital / initially no faults found / all filters found 'dirty' / A similar occurrence was reported 2 Dec 2002 on G-TTOB. (MOR not raised). Galley filters were found blocked with an excessive amount of dirt and dust. Airbus provided an analysis of the filter contents and confirmed nothing abnormal / The operator is sampling other aircraft and will review the frequency of the galley filter replacement as part of the monthly reliability review / initially not on CAA database- refer MOR 200203738 & see ASR 98/02/320, 88/02/320
20-May-2002	EMB145	200203365	Acrid odour in cabin / Air stairs hydraulic actuator failed

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30-May-2002	A320	200203738	G-TTOB ASR 88/02/320 / Cabin crew in rear galley unwell - dizziness, headaches & minor difficulty breathing / more pax than usual sleeping for time of day / cabin crew rotated to f/deck for 02 which helped / galley filters & recirc filters clogged / Operator conducting cabin air quality monitoring checks on fleet / Airbus provided analysis of filter contents finding nothing abnormal / see 2 dec 2002 (same aircraft) see 200203155 & 20034527 & see ASR 98/02/320, 88/02/320
3-Jun-2002	EMB145	200203641	Noxious fumes in pax cabin during pushback / RH condenser & RH engine fan plug seal changed / same aircraft as MOR 29/9/02 & 2/5/02
5-Jun-2002	B777		G-ZZZE / ASR / Hazy oily smoke
6-Jun-2002	EMB145		Reference made to fumes being same as those on 2/5/02 - MOR 200202802
10-Jun-2002	BAe 146		G-JEAU / LHR-LYS / AF 3049. Cabin Crew reported bad air quality towards rear. No fault found.
13-Jun-2002	B757		Fume event- G-BYAY
14-Jun-2002	BAe 146	200203906	G-JEAY / EDI-LCY / BE 755. Acrid fumes on flight deck. P2 felt dizzy and unwell RTB./ 02 / PAN / EDI-LCY / G-JEAY / AAIB 2002/06/14
14-Jun-2002	BAe 146	200204203	Not listed as incident in CAA reviews. Ref 200203906 - Same problem & same aircraft as 2000203906 (same day) / AAIB -refer MOR 7/7/01
15-Jun-2002	B757		Fume event- G-BYAY
15-Jun-2002	B757		Fume event- G-BYAY
24-Jun-2002	B757		Fume event- G-BYAY
24-Jun-2002	B737-4		G-BSNW / ASR
28-Jun-2002	B757		Fume event- G-BYAK
9-Jul-2002	B757	200204664	G-BPEE / IST-LHR / ASR / MOR / O2 USED / Effects on P1 & cabin crew / AAIB / Thick blue smoke & scorched oil fumes on push back after APU shut down for 5 secs & during initial climb for 3 to 4 minutes after (engineering confirmed cause to be APU) and Capt had elected to continue / 02 & goggles used / Both pilots had mild throat irritation & P1 eye irritation & P2 mild headache / BAHS (British Airways Health Services) / PAN / Some cabin crew used oxygen masks.
17-Jul-2002	B757		Fume event- G-BYAH
17-Jul-2002	B757		Fume event- G-BYAH
28-Jul-2002	B757		Fume event- G-BYAH
1-Aug-2002	B757		G-CPES / LHR-AMS / SEE RETURN SECTOR REFERNCE SAME DAY
1-Aug-2002	B757		G-CPES / BA0429 / AMS-LHR / ASR / Hot oil smell on flight deck during take off run and for next 3 to 4 minutes. Smell lingered at low intensity for duration of flight. Fumes on previous sector as well cited as 'more pronounced but cleared rapidly within 2 minutes / Crew considered fumes as discomfort only. No fault found
2-Aug-2002	B757		Fume event- G-BYAH

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3-Aug-2002	B757		Fume event- G-BYAH
13-Aug-2002	B757		Fume event- G-BYAH
14-Aug-2002	B757		Fume event- G-BYAH
17-Aug-2002	BAe 146		G-JEAS / BHX-BHD / BE 402. Metallic smell in cockpit & cabin. Pack 1 suspected. No fault found. G-JEAS
22-Aug-2002	B757		Fume event- G-BYAU
23-Aug-2002	B757		Fume event- G-BYAU
1-Sep-2002	EMB145	200206869	2 cabin crew members unwell with breathlessness, dizziness, popping ears & sickness (like hypoxia) / no fault found but suspected fumes via air con system as tail wind start
18-Sep-2002	EMB145	200206927	Cabin crew report light headedness & dizziness in climb / residual oil contamination after replacement of APU
22-Sep-2002	EMB145	200207274	Strong smell of burning oil on f/deck & cabin / residual oil contamination following replacement of engine & APU / All crew had headaches, sore throats & coughing / Package of modifications to engine available to improve oil sealing properties / mods have taken place over recent overhaul shop visits (see MOR 200200856) / Pneumatic ducting from the engine bleeds was not being cleaned so three was a tendency to have minor air contamination reports post rectification / A process to clean ducts as a routine activity whenever fume related defects are rectified
29-Sep-2002	EMB145	200207276	Cabin crew short of breath & feeling sick, light headed / PAN / AFS / hydraulic air stairs actuator leaking / Blood samples not taken as per CAA recommendations as no specialist unit avail until following day
1-Oct-2002	A319		G-EUPT / ASR / MOR / BCN-BHX / BA1797 / Symptoms reported by cabin crew included sore heads and eyes / No fault found / Aircraft has history of fumes back to May 2002.
3-Oct-2002	B757		Fume event- G-BYAS
5-Oct-2002	B757		Fume event- G-BYAS
6-Oct-2002	B757		Fume event- G-BYAS
14-Oct-2002	B757		Fume event- G-CDUP
18-Oct-2002	B757		Fume event- G-BYAI
21-Oct-2002	B757		Fume event- G-BYAL
29-Oct-2002	B757		Fume event- G-BYAW
30-Oct-2002	B777		G-VIIS / ASR / MOR / Acrid burning smell during climb / APU seal & oil contaminating ducts
1-Nov-2002	B757		Fume event- G-BYAX
8-Nov-2002	B757		G-BKIT- fumes (refer 10/11/02 serious incident) fumes seen to be nearby aircraft. No ASR / MOR
9-Nov-2002	B757		G-BKIT / fumes (refer 10/11/02 serious incident): Engineering requested 'report further'. Further report was on the incident flight-No ASR/MOR

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10-Nov-2002	B757	200208123	CAA SERIOUS INCIDENT: G-BIKT / BA 1384 / PAN declared due to an oily / burning smell in the cockpit / 02 / Acft returned. AAIB-EW/G2002/11/10- left engine replaced
13-Nov-2002	BAe 146		G-CFAB / BA 1643 / engine 4 s/down with incr oil press- decr qty / PAN
20-Nov-2002	B767		G-BNWO / BA62 / acrid fumes on flight deck / cooling exhaust fan c/b tripped / bearing failure
21-Nov-2002	EMB145	200208484	PAN / smoke in cockpit
22-Nov-2002	B757		Fume event- G-BYAI
22-Nov-2002	B757		Fume event- G-BYAI
22-Nov-2002	B757		G-BIKR / oil fumes with L/pack on
26-Nov-2002	B757		G-BPED / short duration on s/up of strong metallic oil smell
27-Nov-2002	B757		Fume event- G-BYAL
29-Nov-2002	B757		Fume event- G-BYAI
1-Dec-2002	A320		G-EUPN / ASR / LIN-LHR / BA0569 / Tech log 05/0853/01 / Nr 2 pack inlet found contaminated, cleaned.
1-Dec-2002	A320		P1 had headache, dizziness, running nose, felt jumpy, diff concentrating / Pax at rear also unwell / Similar on return sector / ASR
2-Dec-2002	B757		Fume event- G-BYAL
2-Dec-2002	A320		G-TTOB / No MOR raised / (see MOR 200203155) / Refer MOR 200203738 on 30/5/02 - cabin crew in rear galley report dizziness with strange odour / referenced MOR only / similar symptoms in 2 other ASR's / galley & recirc filters found blocked / Airbus provided analysis of filter contents & confirmed nothing abnormal
10-Dec-2002	B757		Fume event- G-BYAK
10-Dec-2002	BAe 146		Exhaust fumes smell in FD and in cabin. No1 pack switched off, smell was eliminated only returning when pack reinstated. Remainder of flight operated with pack 2 only. No fault found. G-JEAJ
14-Dec-2002	B757		Fume event- G-BYAK
15-Dec-2002	B757		Fume event- G-BYAK
20-Dec-2002	B757		Fume event- G-BYAK
20-Dec-2002	B757		Fume event- G-BYAK
21-Dec-2002	BAe 146		G-JEBA, NCL-CDG. BE 3021. No2 Cabin Attendant burning streaming eyes in rear of cabin and alleviated whilst working at the forward cabin. Symptoms returned when working rear cabin./ No fault found. Eng said acft had been de-iced before flt.
26-Dec-2002	B757		Fume event- G-BYAL
26-Dec-2002	B757	200209220	ASR / MOR / ATH-LHR / BA631 / BA FOSU REPLY / G-CPES / Strong oil smell on f/deck after start and on take off & climb. Oxygen not used as smell gone very soon after take off and both crew 'appeared' to suffer no ill effect. No fault found - "incident probably not unique"

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27-Dec-2002	BAe 146	200209255	Acrid fumes in cabin / crew & ground staff noted burning & choking feeling in throats / fluid leaked in hydraulics bay causing noxious fumes
28-Dec-2002	B757		Fume event- G-BYAL
29-Dec-2002	B757		Fume event- G-BYAK
30-Dec-2002	A320		G-BUSF / BA964 / LHR-HAM / ASR / At the end of the landing roll with reverse idle selected, slight smoke and smell noticed in flight decek. Smoke density increased markedly as aircraft exited runway. CSD reported significant smoke in the cabin. Runway had been de-iced and crew suspected fluid ingestion. Note: There are several reports like this even in summer time so this may or may not be the cause of this event.
31-Dec-2002	BAe 146	200209275	Smoke & fumes in f/deck / Mayday / 02 / AFS / cabin crew informed by passengers / no fault found but PSROV valve replaced just before incident
1-Jan-2003	A320		P1 - headache- loss of concentration- runny nose- twitchy sensation- pax unwell in the rear cabin. Same capt as Dec 2002 incident. Since then flown 1000 hrs on type with no particular incident but regularly noticed unusual smells - plastic - old socks - detergent...
2-Jan-2003	A319		G-EUPJ / ASR / LHR-HEL / BA0794 / At approximately Acceleration altitude a strong burning smellwas detected at the rear of the aircraft / decreased with pack 2 off / no fault found
2-Jan-2003	A321	200300009	Noxious fumes on flight deck and in pax cabin. 'Significant' oil leakage across the APU load compressor carbon seal and subsequent contamination of the bleed air
10-Jan-2003	B757		Fume event- G-BYAK
12-Jan-2003	B757		Fume event- G-BYAJ
20-Jan-2003	A320	200300367	Blue smoke haze & irritating smell of burnt dust in cabin / Suspected air conditioning pack condenser coating / doors opened & packs operated to clear smell
24-Jan-2003	BAe 146	200300540	Contamination of air conditioning system (extremely strong fumes) suspected contaminated with de-icing fluid (not enough info to support this)
27-Jan-2003	BAe 146		G-JEAY / LGW-GCI / BE 909A. Air Con fumes in Cabin & FD. Taxing in @ LGW after approx 5 mins of APU running and approx 3 mins after switching to APU Air. Packs turned off. Smell in Cabin 35 mins later. No fault found - G-JEAY
28-Jan-2003	BAe 146		Air Con smell when power inc at 5000 for further climb. Pack burn for 15 mins. No fault found. (referred to in above) G-JEAY
28-Jan-2003	BAe 146		G-JEAK / LHR-TLS / AF 3043. Cabin felt sick on approach linked to air change from ENG to APU / Significant smell identified. No fault found. G-JEAK
10-Feb-2003	BAe 146		G-JEAU / LYS-LHR / AF 3048. Whilst on approach at LHR, Cabin Crew reports heavy Smell, then after a couple of seconds, Smoke coming out of Air Conditioning System at the rear of the cabin. Pack 2 immediately shut by Captain. Smoke Stops. After a few selections of Pack 2 on the ground, with no smoke occuring, Captain decides to carry on with next sector. On arrival at LYS however, Captain gets Sore Throat and F/O and No3 Cabin Crew headaches.

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15-Feb-2003	B737	200300933	De-icing commenced without warning, (de-icing fluid contacts hot APU exhaust gas) leading to fumes and smoke entering the aircraft / AFS
17-Feb-2003	B757		G-CPEL / BA1472 / LHR-GLA / Both pilots and some cabin crew smelt fumes / O2 not used due to workload Oil levels adjusted to nominal, one litre drained from each engine.
20-Feb-2003	B757		G-CPEM / BA 349 / fumes
24-Feb-2003	BAe 146	200301205	Smell of smoke on flight deck with smoke visible in cabin.
9-Mar-2003	B777		G-YMMG / ASR / MOR - smoke / haze "oily rag smell"
19-Mar-2003	B757		G-BPEI / FCR / BA1458 / LHR-EDI-LHR / Fumes on both sectors. Engineering investigation in EDI with fumes on return / 02 / ASR
21-Mar-2003	EMB145	200301778	1 cabin crew member suffered allergic reaction from unspecified source which caused eye irritation
21-Mar-2003	EMB145	200301843	Faint odourless mist on t/off & taxi in /no fault found
24-Mar-2003	B757		BA FCR / G-CPEO
30-Mar-2003	A319		ASR / MOR / G-EUOF / OSL-LHR / BA0767 / Tech log 04/0513/01 Descending through 2500 ft a strong smell of chemicals permeated the flight deck and also the cabin. Smell remained until passing through 500ft, clearing by touchdwon. Cabin crew reported the smell as noticeable and worst towards the front of cabin. First officer donned oxygen mask at 2000 fee as a precaution until fumes cleared. mask removed at 500 feet. No fault found
1-Apr-2003	B757	200302053	G-CPET / ASR / MOR / BA479 / BCN-LHR / O2 Used / In cruise at 36,000feet oily smell noticed by co-pilot. Crew actioned the QRH. No fault found nor in previous Jan 2003 event on same aircraft.
1-Apr-2003	B757		(G-CPER incident report) / sporadic reports of oil fumes. No other data found / 02 / (spinner fairing found cracked)
4-Apr-2003	EMB145	200302131	Smoke on f/deck & cabin / APU major bearing failure / P1 & 1 cabin crew later reported sore throats & dizziness / medical advice sought
8-Apr-2003	B757		FCR / G-CPEO / BA712 / fumes on t/off
14-Apr-2003	B757		Fume event- G-BYAN
17-Apr-2003	B757		Fume event- G-BYAN
17-Apr-2003	B757		Fume event- G-BYAN - pilot had a week off with throat infection after this incident
17-Apr-2003	A320	200302553	G-VCED / Burning smell in rear cabin / no obvious fault / galley vent filters removed & cleaned
22-Apr-2003	A320	200302384	Blue/grey smoke in cabin as thunderstorm passed / APU failed / AFS
23-Apr-2003	B757		G-CPER / BA 939 / oil fumes
25-Apr-2003	B757		Fume event- G-BYAN
25-Apr-2003	B757		Fume event- G-BYAN
27-Apr-2003	B757		G-BPEJ / BA 503 / oil fumes
28-Apr-2003	A320	200302509	Haze & fumes in rear cabin / cabin crew unwell / PAN / reporter suggested condensation from air con system as bad weather

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18-May-2003	A319		G-EUPP / BA 0778 / ASR / LHR-ARN / Shortly after Top Of Descent captain noticed a faint oily smell. Co-pilot could smell nothing. Some minutes later a cabin crew member reported smells. No fault found
5-Jun-2003	B757	200303506	BA FCR / G-CPET / ASR / MOR / BA641 / ATH-LHR / O2 USED / PAN / BAHS (British Airways Health Services) informed / Acrid fumes on descent passing 10000 feet. Flight crew believed smell was due to contamination of the airconditioning from engine oil.
7-Jun-2003	EMB145	200303689	Faint oily smell in cabin / 2 cabin crew unwell as light-headed, nauseous & headaches (used cc 02) / no fault found. Similar smell 3 days later on same aircraft (gas odour) / airline suspects faulty galley urn (not enough info to support this)
13-Jun-2003	A320	200303690	Smoke in cockpit / Mayday
14-Jun-2003	EMB145	200303777	Large qty of blue smoke & fumes in f/deck & cabin / Pax disembarked / AFS / Ground power cart suspected (not enough info to support this)
16-Jun-2003	BAe 146	200304454	G-BZAX / BA1616 / ASR & MOR / smoke & fumes on flight deck (tech log history of fumes & smoke) / 2 Engine bearing failure. Fire services; Engine was not to the latest modification standard and did not include the number 2 bearing improvements
20-Jun-2003	B777		ASR / G-VIIM / fumes & haze / no fault found
22-Jun-2003	B757		ASR / MOR / G-CPEO / LHR-LIS…..SEE REFERNCE IN RETURN SECTOR SAME DAY.
22-Jun-2003	B757		ASR / MOR / G-CPEO / LIS-LHR / BA503. At 1200 feet both pilots noticed an oil smell in the flight deck. Oxygen not used as landing was assured. Fumes on previous sector / pilots concerned of LT effects / high oil consumption on left engine
23-Jun-2003	B757		ASR / MOR / G-BPED / PAN/ ADO & EIR / 3 cabin crew members unwell with one having headache throughout sector "During approach, a chemical / metallic smell was noted by 3 crew members in the rear galley area. This caused one of the crew to suffer a headache, although following a rest after landing, she was able to continue her duties. Subsequent inspection revealed oil dripping from the Left Hand pack bay area, with oil leaking from the air cycle machine into the pack bay."
29-Jun-2003	BAe 146		In descent P2 informed P1 felt unwell & P1 to take control / P2 then sick. Fumes not mentioned. G-JEBE
9-Jul-2003	EMB145	200304724	P2 reports periodic hot plastic smell with slight irritation & momentary shortness of breath / no fault found
13-Jul-2003	A320	200304527	4 out of 5 cabin crew members were physically sick over a ten minute period during the climb / Aircraft returned / Doctor & airport health authorities suggested C02 type poisoning / 3 passengers also nauseous on landing / cabin crew hospitalized & thought to have C0 poisoning / pilots & passengers reported no illness / further medical examinations showed that the traced levels within the affected crew were well within safe limits and would not have caused the ill effects. Further investigations have taken place including an in depth survey (environmental and questionnaire) of a cross section of the operator's fleet and crew, conducted by a specialist aviation air quality team from Building Research Establishment (BRE). A recent presentation of the results concluded that the surveys carried out showed no unusual results and were typical of other surveys carried out by the team. Air quality levels were within health based standards / guidelines and should not present health risks / initially not on CAA database - refer MOR 200203738 /

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17-Jul-2003	B757		G-CPEO / BA304 / LHR-CDG / From T/O to 5000 ft strong acrid smell of oil / O2 not used as smell had dissipated. Both engines found to be overfilled with oils.
21-Jul-2003	A319		G-EUPX / ASR / BA919 / STR-LHR / Smells in the flight deck for approximately 3 minutes and in galley for 45 seconds. No fault found
27-Jul-2003	B757	200305002	ASR / MOR / G-BPEK / strong smell of oil - vomit / both pilots Used O2 / PAN / no fault found / 3 cabin crew & 2 pax aware of sick like smells
27-Jul-2003	B757		G-CPER / ASR / LHR-ATH ….SEE ENTRY ON RETURN SECTOR ASR SAME DAY
27-Jul-2003	B757	200305003	G-CPER / ASR / ATH-LHR / BA641 / O2 USED / crew unwell. Faint flight deck oil smell on taxi out. Increased on take off. QRH actioned after flaps retracted. Contamination on previous sector
27-Jul-2003	B757		G-BPEK / BA465 / MAD-LHR / ASR / MOR / In hold at 10,000 feet flight crew noticed a sudden strong smell of oil/vomit.Fumes drill carried out and oxygen masks donned. PAN declared. After 5 minutes F/O took mask off but fumes still present. No fault found.
29-Jul-2003	B757	200305055	G-CPER / ASR / MOR / BA307 / CDG-LHR / 1 other recent report / 10 sec burst of smells after take off.
30-Jul-2003	B757	200305082	APU had failed and had dumped oil into the air conditioning system causing the smoke. failed load compressor & oil seals in APU
1-Aug-2003	BAe 146	200305115	BAe 146-200 / G-MANS / MOR / Belfast to MAN / smoke- blue haze- mist- fumes- emergency evacuation; Media article (MOR-oil seal in the APU had allowed lubricating oil to pass into the air stream.) - CAA closure - NO CAA action appropriate The aircraft was about to commence a scheduled flight to Manchester from Belfast City Airport with a crew of 5 and 53 passengers. The 5 crew had boarded the aircraft and started the APU, which was used to provide an air supply to the air conditioning packs as well as electrical power for the aircraft systems during a turn round. As the safety brief was completed, the cabin crew became aware of a smell of fumes and could see smoke appearing which seemed to be worst towards the rear of the cabin. The aft cabin attendant moved to the forward galley immediately behind the flight deck to discuss the situation with the Senior Cabin Crew Member (SCCM). The SCCM contacted the aircraft commander on the interphone and reported the presence of the smoke and fumes and also explained that the passengers were aware but were not alarmed. No smoke or fumes were present on the flight deck.... The report from the SCCM indicated that the situation was getting worse, that the passengers were becoming agitated and the cabin crew were not happy to taxi back to the stand. The commander warned the SCCM to be ready for an emergency evacuation, instructed the FO to carry out the emergency evacuation drill and completed his own memory items which included a public address announcement ordering the evacuation.
10-Aug-2003	A320	200305381	Noxious irritating smell on f/deck shortly after take off / 02 / PAN / overhead vent fan contaminated with oily residue & had seized
12-Aug-2003	B757	200305515	G-BPEJ / BA455 / ASR / MOR / MAD-LHR / 02 USED / Passing approx 12000 feet in descent both pilots were aware of an increasingly strong oly smell. Pilots reported 'mild symptoms normally associated with fumes including sore throats' & P1 developed bad headache that night / AAIB informed / P1 advised that he often smells oil fumes on t/off on G-CPER
14-Aug-2003	B767		G-BNWT / BA047 / ASR & MOR / PAN / 02 / Diversion / acrid smell / no source

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14-Aug-2003	B757		G-BPEJ / BA455 / MAD-LHR / ASR / 2 x 30 secs oil smell bursts.
15-Aug-2003	B757		Fume event - G-BYAT
17-Aug-2003	B757	200305699	O2 USED / smoke in flight deck / Air cycle machine failed (acrid sulphurous smell & smoke. 'current reliability on this component is within acceptable levels'
22-Aug-2003	B757		Fume event - G-BYAT- GI symptoms
22-Aug-2003	B757		Fume event - G-BYAT- GI symptoms
23-Aug-2003	B757	200305775	ASR / MOR / G-BPEJ / BA1313 / ABZ-LHR / O2 USED / PAN / Passing 22,000 feet on descent into LHR, very strong smell of oil on flight deck. Crew effects by pilots & cabin crew - All crews to BAHS (British Airways Health Services) - fumes also smelt by groundd engineers & dispatcher. Crew advised "must be something you ate" APU was found to be source of fumes and was replaced.
25-Aug-2003	B757	200305917	G-CPEN / BA564 / ASR / MOR LHR-LIN / By 3000 feet oil could be "smelt and tasted." Flight stated oil consumption on right engine was high. No fault found
28-Aug-2003	B757		G-CPEN / BA553 / LHR-FCO....SEE ENTRY ON NEXT SECTOR SAME DAY.
28-Aug-2003	B757		Referred to in CAA ref 20035917 / G-CPEN / BA553 / FCO-LHR / ASR / MOR Could taste contamination but disspiated before opportunity to execute the QRH. Transient smells on previous sector.
29-Aug-2003	BAe 146		G-JEAS / NCL-CDG. BE 3023. In cruise at FL250- all 3 CA felt unwell- nausea & light headedness. Also after landing, all 3 cabin crew continued to complain of feeling unwell and mentioned that they had felt similar symptoms on G-JEAS on previous flights. No fault found. G-JEAS
29-Aug-2003	B757	200306511	G-BPEJ / BA462 / LHR-MAD / ASR / MOR / Flight suspected air conditioning contamination but did not action the QRH due high workload. 'Tangy heated oil' - Invest not req / Suspect air conditioning contamination / no fault found
2-Sep-2003	B757	200306054	Burning smell & loud bang / Mayday / O2 / diversion / no fault found
5-Sep-2003	EMB145	200306165	Poor cabin air quality - oil contamination fumes from air conditioning smelt / APU unserviceable / Seal deterioration
5-Sep-2003	B757		Fume event - G-BYAL
7-Sep-2003	B757		Fume event - G-BYAL
7-Sep-2003	B757		Fume event - G-BYAL

7-Sep-2003	B757	200306174	G-CPER / LHR-CDG diverted to LGW / SERIOUS INCIDENT / Fumes - O2 - PAN AAIB / ASR- aileron problem / possible overfilling of oil caused fumes / medical follow up? AAIB report critical of airline maintenance practices.Oil fumes on flight deck and in cabin. PAN declared and crew donned oxygen masks. Aircraft diverted to LGW. Control difficulties on approach. Maintenance errors. AAIB Formal investigation. AAIB Aircraft Accident Report 3/2005 - Summary: The incident to the Boeing 757 aircraft occurred on the first flight following a 26-day major maintenance check. Shortly after take off on a scheduled passenger flight from London Heathrow to Paris, a hot oil smell, that had been present in the cockpit on engine start up, returned. The flight crew donned oxygen masks and immediately diverted to London Gatwick Airport. During the autopilot-coupled ILS approach to Gatwick, the aircraft drifted to the right of the localiser after selection of Flap 30. When the autopilot was disconnected, a large amount of manual left roll control was needed to prevent the aircraft from turning to the right. It was necessary to maintain this control input until touch down. The aircraft landed safely despite these difficulties, with no injuries to any of the passengers or crew. Investigation determined that the incident had been caused by maintenance errors that had culminated in the failure to reinstall two access panels, 666AR & 666BR, on the RH outboard flap and incorrect procedures being used to service the engine oils. The events were the result of a combination of errors on the part of the individuals involved and systemic issues, that had greatly increased the probability of such errors being committed. The following immediate causal factors were identified: 1) The tasks of refitting the panels to the right wing and correctly certifying for the work carried out were not performed to the required airworthiness standard; 2) Ineffective supervision of maintenance staff had allowed working practices to develop that had compromised the level of airworthiness control and had become accepted as the 'norm'; 3) There was a culture, both on the ramp and in the maintenance hangar, which was not effective in ensuring that maintenance staff operated within the scope of their company authorisation and in accordance with approved instructions; 4) The maintenance planning and task instructions, relating to oil servicing on the Boeing 757 fleet, were inappropriate and did not ensure compliance with the approved instructions; 5) The airline's Quality Assurance Programme was not effective in highlighting these unsatisfactory maintenance practices. Eight Safety Recommendations (2005-116 to -123) are made in the report, with the intention of preventing similar incidents in the future. CAA Closure: CAA FACTOR F43/2005 was issued on 15 December 2005.

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8-Sep-2003	BAe 146	200306167	BA4325 / IOM-LGW / G-MIMA / Sn 2079 / MOR. At LGW timed at 14 25pm (GMT) Serious Incident. Fumes in flight deck- cabin during emergency evacuation. 2 passengers injured. AAIB. APU bearing failure which led to damage to a carbon oil seal, which allowed hot engine oil to enter the bleed air air stream and subsequently enter the cabin as (thick blue) smoke/fumes. CAA Closure: The hazard is acceptable provided the frequency of occurrence remains low. After shutdown, following an uneventful flight, smoke/fumes appeared in the cabin and on the flight deck as the passengers were disembarking. Without a specific checklist or training to cover this situation, the crew followed the evacuation checklist, with the exception of firing the APU fire bottle as they initially thought the origin of the smoke was in the avionics bay. They also completely de-powered the aircraft. The source of the fumes was traced to the recently replaced APU, where the main rotor bearing appeared to have suffered a cage failure. This in turn led to damage to a carbon oil seal, which consequently allowed hot engine oil to enter the bleed air airstream and subsequently enter the cabin as smoke/fumes. The APU manufacturer has undertaken the investigation of the cause of the bearing failure.
10-Sep-2003	B757		G-CPEM / BA561 / 2 mins smell of oil on take off / O2 not used & no ASR as event not considered serious- part of continuing problem
21-Sep-2003	B757	200306630	G-CPER / BA955 / strong fumes in climb & descent / O2 USED / ASR / MOR / PAN / Dryness in the mouth with slight soreness and mild headache / pax ok / AAIB to make full report -refer MOR of 26/12/03 / recurring problem
26-Sep-2003	EMB145	200306842	APU failure led to light smoke & fumes in f/deck (failure of main bearing is a known problem)
26-Sep-2003	B757	200306777	BA FCR / G-CPET / ASR / MOR / BA 875 / DME-LHR / Effects: Capt & 2 CC reported light headed- headaches & burning noses / BAHS (British Airways Health Services) cleared for return sector from DME.Dept lounge PA gave "rather honest reason for delay as fumes/smoke in aircraft" Therefore Capt "had to give equally honest PA on boarding to explain delay and how the problem was now made safe" . engineering found no obvious oil leaks & suspected defect may be linked to high oil consumption in right engine which had a history of this
27-Sep-2003	A320		G-EUUB / BA853 / PRG-LHR / ASR / 'cheesy wet shirt smell' / no fault found. Flight crew suspected smell due to engineering topping up oils overnight
27-Sep-2003	B757		Fumes
28-Sep-2003	EMB145	200306844	Strong nauseating fumes on f/deck leading to headaches & throat irritation / No. 1 fuel nozzles replaced but not considered by manufacturer to have caused crew incapacitation & fumes checklist
29-Sep-2003	A320	200306904	Oil mist in cabin with oil filter clogged & low oil pressure warnings / No. 3 bearing failed
3-Oct-2003	B757		Fume event - G-BYAJ
4-Oct-2003	B757		Fume event - G-BYAJ

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4-Oct-2003	Concorde	200306934	G-BOAC / BA001 / failed CAU- oil mist & fumes-"oil sealing system is far from perfect"/ 02 / Air & smoke warnings appeared intermittently / ASR / MOR / serious incident / AAIB / oil seal diaphragm and bearing failure
15-Oct-2003	A320		Refer MOR 200302553 / recirc fan MEL'd & replaced
22-Oct-2003	BAe 146	200307393	Hydraulic vapour in cabin / hydraulic fluid leak in hydraulic bay / Engineering Review notes that in the absence of such an event on Company fleet, SB 53-BAe 146-30497A for improved sealing of the hydraulic bay to prevent pax cabin contamination in the event of hydraulic bay leaks issued 3 years earlier was not actioned. Embodiment to be considered by Operator. CAA Closure: The hazard is acceptable provided the frequency remains low. (AD on this issued in 1984)
30-Oct-2003	EMB145	200307561	Sickly oil fumes on f/deck /APU seal failed
31-Oct-2003	B757		Fume event - G-BYAU
1-Nov-2003	B757		Fume event - G-BYAU
1-Nov-2003	B757		Strong oily fumes / P1 used 02 as light headed / P2 had some nausea & used 02 / BAHS (British Airways Health Services) agreed OK to do return sector as effects gone
7-Nov-2003	EMB145	200307886	Fuel type smell after push back / Smelt by cabin crew & pax / cabin crew felt unwell with stomach sickness / Fault with engine fuel nozzles
18-Nov-2003	B757		Fume event - G-BYAX
19-Nov-2003	B757		Fume event - G-BYAX
19-Nov-2003	B757		Fume event - G-BYAX
19-Nov-2003	B757	200308056	G-BPEI / BA1465 / ASR / MOR / EDI-LHR / O2 USED / ASR / Fumes observed in the flight deck passing 10000 feet in the climb. Oxygen used until 15000 feet when smell had disappeared. No fault found
19-Nov-2003	B757	200308081	G-CPES / BA 676 / LHR-IST return to LHR / O2 USED / ASR / MOR strong smell of oil in flight deck after rotation. At 10000feet smell still remained and crew experienced physiological effects so oxygen then used and QRH actioned. Part of AAIB invest of 7/9/03
20-Nov-2003	BAe 146	200308306	G-JEAK / TLS-SOU / BE 1702 / In Climb from TLS, Cabin Attendant reported strong fumes "petrol type fumes". Eng said: No fault found - must have been cleaning fluids (no validation for this & MOR does not support this) - G-JEAK / ISB carried out & air quality monitored
24-Nov-2003	EMB145	200308193	De-icing fluid thought to be cause of fumes in f/deck
25-Nov-2003	B757	200308222	Smoke in cockpit / no fault found
27-Nov-2003	B757	200308277	G-BPEJ / BA1486 / LHR-GLA / O2 Uused / P1 Unwell / ASR / Fumes also on 1st flight of day ex LHR / Part of 7/9/03 AAIB

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28-Nov-2003	A320	200308283	G-BUSF / MOR / ASR / BCN-LHR / Strong short oil smell in flight deck and cabin / felt pressure to operate next 2 sectors due shortage of aircraft / Repeat smells on approach & refused aircraft for next sector / Made to explain reasons for action directly to management / engineering found: 1) A significant amount of oil was noticed coming from the engine compressor. 2) Oil was noted in the APU air intake radiating out from the engine compressor. 3) Oil was seen coming from the engine compressor split line. The cause of failure was traced to the de-oil solenoid which failed in the open position allowing oil to drain back to the E/C seal and into the inlet plenum. This is a known and rare condition and the embodiment of SB 49-7617 will eliminate any risk from this oil leak path. APU was replaced with air conditioning purge.
28-Nov-2003	B757	200308287	G-BPEJ / BA9280E / GLA-LHR / ASR / MOR / O2 used After right engine start, with both packs selected off slight fumes in the flight deck. On descent P1 felt light headed & P2 had a tingling sensation in fingers & lower arm so oxygen used
7-Dec-2003	B757		Fume event - G-BYAP
13-Dec-2003	B757		G-CPER / BA423 / Very oily smell up to 6000ft. No 02 used as considered transient
16-Dec-2003	A320	200308745	Air Safety Week & MOR: Enroute LGW-Marrakech / Diverted Nantes 45 mins ex Gatwick due smoke & fumes in cockpit, cabin (noticed by crew & pax) / no fault found / CAA closure 'The hazard is acceptable provided the frequency remains low'
21-Dec-2003	B757	200308854	G-CPEM / ASR / MOR / BA676 / LHR-IST / O2. Oil fumes in f/deck on take off & climbfor several minutes. Captain felt unwell then FO briefly also / ASR / BA676 / BAHS (British Airways Health Services) advised before rt sector / No fault found
23-Dec-2003	B757		Fume event - G-BYAX
24-Dec-2003	A320	200308963	Increasingly strong burning smell & haze throughout aircraft on t/off / Mayday / ACM failed (which was cause of fumes) as well as another unrelated defect /
26-Dec-2003	B757	200309019	G-CPER / BA875 / ASR / MOR / DME-LHR / Chemically oily smell after start when packs selected on / capt unwell / Oil level down / no fault found / similar event on previous sector
31-Dec-2003	A320		G-BUSH / ASR / LHR-OSL / BA766 Smoke and fumes in cabin and flight deck after landing with reverse thrust on icy / slippery runway. Note: Several events like these even in summer time.
1-Jan-2004	B757	200400010	G-BPEJ / ASR / MOR / LHR-AMS return to LHR / BA434 / O2 USED / PAN Crew noted fumes in flight deck during climb- followed by cabin crew & a pax reporting fumes in the forward cabin. Flight crew suspected left pack as smells returned with power increase on final approach.
5-Jan-2004	EMB145		Fumes reported- see following event same day / Refer CAA MOR 200400041

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5-Jan-2004	EMB145	200400041	Strong fuel fumes in f/deck & cabin following APU start & taxi / flight crew had been made aware of this event as engineering had notified them of a possible malfunction from the previous sector. Defect reported day after APU replaced for unrelated problem. Possibly related to start purge valve.
6-Jan-2004	B757	200400112	G-BPEI / BA1403 / ASR / MOR / MAN-LHR Oily smell in flight deck & cabin / oxygen about to be used when smell dissipated
7-Jan-2004	B757	200400196	ASR / MOR / G-BPEI / LHR-BRU / BA388 After take off and then climb, cruise and when power applied during intermediate approach both pilots noticed oily smell on the flight deck emigating from the air conditioning. Cabin crew throat irritation / P1 & P2 nauseous / Aircraft dispatched with MEL pack off / 02 not considered nec. Aircraft has history of defects ref maintenance logs / Crew ASR'd fumes day before
7-Jan-2004	B757	200400196	Oily smell on flight deck / both pilots felt nauseous temporarily /aircraft dispatched under MEL with one pack off
9-Jan-2004	B757		Fume event - G-BYAX
9-Jan-2004	B757		Fume event - G-BYAX
9-Jan-2004	BAe 146		CC member fainted and found by pax in toilet. Fumes not reported. G-JEAX
12-Jan-2004	BAe 146	200400144	Burning smell in flight deck.
12-Jan-2004	BAe 146	200400144	Burning smell in flt deck & cabin at rear of a/c - LHR-LYS - G-JEAK / burning smell in f/deck & plastic burning smell at rear
12-Jan-2004	BAe 146		G-JEBD / BHD-BHX, BE 415. Strong fumes smell on change from APU to Eng air after T/O.P2 later > headache- dry eyes- tingling-arms/legs. G-JEBD not considered reportable under MOR scheme / no tech log entry made by crew therefore no engineering investigation
12-Jan-2004	BAe 146	200400144	G-JEAK / LHR-LYS / AF 3045. Burning smell in flt deck & cabin at rear of a/c - LHR-LYS - G-JEAK / burning smell in f/deck & plastic burning smell at rear of a/c from left hand side. Pack 2 and Galley turned off. Smell disappeared.
13-Jan-2004	B757	200400213	G-CPES / P2 USED O2 USED / ASR / MOR / LHR-ATH / BA640 / Oxygen / Transient fumes after take off with first officer going onto oxygen / possible oil overfilling otherwise no fault found
17-Jan-2004	B757		Fume event - G-BYAX
17-Jan-2004	B757		Fume event - G-BYAX
18-Jan-2004	B757		Fume event - G-BYAX
18-Jan-2004	Dash 8	200400332	Manchester / Pretitle : Haze reported in cabin. / Precis : During taxi, cabin crew advised of a progressively thickening haze moving through the cabin. As the aircraft returned to the stand, with fire services in attendance as a precaution, nr1 bleed was deselected which resulted in the haze dissipating. No fault was found and it is suspected that the haze was caused by the ingestion of de-icing fluid on initial start.
18-Jan-2004	BAe 146	200409536	G-JEBB / BHX-BHD BE 416. Strong oil smell on change over from APU to Engine air after T/O- Headache- Tingling in legs after arrival in BHD. G-JEBB / not considered reportable under MOR scheme

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19-Jan-2004	B757		Fume event - G-BYAX
19-Jan-2004	B757		Fume event - G-BYAX
20-Jan-2004	B767	200400351	G-BNWX - oily smell / ASR / MOR
24-Jan-2004	B767		BA631 / strong oil fumes in descent / 02 / PAN / ASR / MOR / BAHS (British Airways Health Services) verbal advice; seek fresh air and report sick for 24 hours if feeling unwell/headaches / P2 attended BAHS as distinctly unwell
25-Jan-2004	A320	20040455	G-BUSB / ASR & MOR / BA816 / Strong oil fumes in cabin & flight deck / O2 / LHR-CPH Return to LHR - PAN / Cabin crew unwell the P1 noticed marked tingling in arms- extreme light-headedness and no ability to focus or concentrate (partial incapacitation). P2 experienced some mild light headedness / ground crew smelt fumes minutes after rt to LHR / seal failed and scavenge pipe leaked /various defects found & listed in MOR in detail -" the combination of defects could produce a source of oil fumes which would enter the gas path and ultimately the aircraft bleeds". MOR understates crew incapacitation degree as p1 effected badly & p2 slightly with the later not mentioned in the MOR and the degree of P1 effects not mentioned
28-Jan-2004	B757		Fume event - G-BYAX
29-Jan-2004	B757		Fume event - G-BYAX
30-Jan-2004	B757		Fume event - G-BYAX
1-Feb-2004	B757		G-CPES / BA640 / Transient fumes on t/o / P2 used 02 / P1 questions mandatory ASR if 02 used due maint work required
3-Feb-2004	B757	200409539	G-CPER / BA1318 / LHR-ABZ / O2 USED / ASR / Both pilots noticed a strong smell on take off roll and during initial climb.
6-Feb-2004	EMB145	200400718	Cabin crew reported burning smell on approach
15-Feb-2004	EMB145	200400895	Smokey air noticed in cockpit during last 3 sectors / slight headaches for both pilots / numerous previous occurrences / concerns about air quality / a/c released for service as no fault found
20-Feb-2004	BAe 146	200401336	Smoke burning smell in cabin / smoke & fluid in hydraulic bay / Damaged O ring in Acpump of hydraulic system
22-Feb-2004	A320		ASR / Fumes / MUC-LHR / BA947 / G-BUSF / During take-off roll, a strong oily smell was noticed by both pilots. Smell persisted until after acceleration altitude / O2 decided not necessary as fumes dissipated. TOGA Take off was being performed.
23-Feb-2004	BAe 146	200401086	G-JEAJ, EDI-SOU, BE 779. Cabin crew reported strong fumes in cabin in climb & 2 went onto oxygen - Flight continued to Sou. G-JEAJ / no fault found on 2 occasions /operator has established an air quality monitoring initiative with frequencies exceeding those listed in TCDS & MRBR recommendations
29-Feb-2004	B757	200401272	G-BPEE / BA1394 / ASR / MOR / LHR-MAN / Fumes on f/deck after take off oil overfill? / Aircraft dispatched serviceable as fumes dissipated in flt and oil drained. This is a known problem & engineers are again reminded not to overfill oil levels and to record all up lifts in tech log.
29-Feb-2004	B757		G-PEE / ASR / MOR / LHR-MAN / BA1394. During take off and initial climb a strong smell of oil detected on flight deck. On landing engines found to be overfilled / strong fumes
2-Mar-2004	B757		Fume event - G-BYAN
2-Mar-2004	B757	200401271	G-BPEE / BA1443 / ASR / MOR / Oil smell after take off / 2 pilots and a cabin crew member had dry cough /

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4-Mar-2004	BAe 146		Cabin crew blacked out - fumes not mentioned. G-JEAW.
8-Mar-2004	B777		ASR / MOR / fumes / smoke / PAN
12-Mar-2004	B757		Fume event - G-BYAS
12-Mar-2004	B737	200401486	Smoke on f/deck on take off / PAN / 02 / air return / de-icing fluid had entered the APU air inlet / both air conditioning packs were operated in all modes with APU and bleed air, until no smell was apparent. aircraft considered satisfactory for service
16-Mar-2004	B757		Fume event - G-BYAS
16-Mar-2004	B757		Fume event - G-BYAS
17-Mar-2004	B757		Fume event - G-BYAS
17-Mar-2004	EMB145	200401640	Burning smell noted in flight deck & cabin
18-Mar-2004	B757		Fume event - G-BYAS
18-Mar-2004	B757		Fume event - G-BYAS
26-Mar-2004	B777		ASR / MOR / Seized ACM / Diversion / acrid fumes
30-Mar-2004	B757		Fume event - G-BYAS
2-Apr-2004	BAe 146	200402057	G-JEBA / BHX-CDG / AF3011. Mayday declared on descent into Paris as thick blue smoke filled the cabin - Oxygen not used. G-JEBA / AAIB bulletin 6/2004 / Capt could barely detect smell or smoke & decided oxygen not required for crew or pax /oil leak from air con pack attributed to oil seal failure and smokey oven in galley Suspect APU. CAA closure - the hazard is acceptable provided the frequency of occurrence remains low - (This is a common statement on the MORs)
13-Apr-2004	BAe 146	200402232	G-JEBH / EXT-FAO-EXT / BE 1551. Smoke & strong pungent smell in cockpit - O2 used / Mayday / Returned to EXT. Hydraulic leak. G-JEBH / MOR - hydraulic fluid leak noted before dept / slight rise in oil consumption & slight oil deposits detected / chip detector cap seals failed / high level of ' cabin air quality monitoring ' by operator & manufacturer with reports reviewed on a weekly basis for adverse trends
13-Apr-2004	B747		ASR / MOR / electrical burning smell/ diversion / Emergency ldg / no fault found
14-Apr-2004	EMB145	200402301	Burning smell from air con (burning plastic?) / security sticker found in core of engine (not enough info to know if this was source of problem)
22-Apr-2004	B757		Fume event - G-BYAH
23-Apr-2004	EMB145	200402622	Burning oil, rubber smells 'WD40' like, which became chemical in nature & intermittent / no fault found / reporter suspects detached security seals (not enough info to support this)
30-Apr-2004	EMB145	200402665	Lav smoke warning in climb / smoke in cabin / PAN / No fault found / Eng suspected visible water vapour from air con system
1-May-2004	B737		Oil smell - no fault found / suspect baggage / ASR / MOR

7-May-2004	B757	200402853	Smoke & haze inside cabin before pax boarding / crew evacuated & fire services called / suspected rain related / Aircraft returned to service but oily burning smell returned through air con system later although still raining.Smoke in cabin whilst aircraft parked on stand prior to passenger boarding. Investigation could not reproduce the effect on the ground and no further reports have been received since. Prior to departure, there was a smell of smoke and a haze was visible from shoulder height up to the cabin ceiling. The cabin crew were immediately evacuated from the aircraft and the P1 called for fire service attendance. The utility busses and packs were selected off and the full shutdown checks were completed. Ground power was then disconnected and the P1 vacated the aircraft to the airbridge to await the fire crew. The aircraft was inspected/cleared by the fire services together with an engineer and then released to service. The reporter comments that at the time of the incident it was raining, the APU had been shut down for approx 30 minutes and smoke appeared 3-4 minutes after the RH pack had been turned on (LH pack off). There was no recurrence of the smoke or smell at destination (where it was dry), but on return to the UK (where it was still raining) and after engine shut down, the reporter confirms that there was a definite oily/burningsmell through the air conditioning system (although no visible smoke this time). Investigation, including examination of the air conditioning system for oil contamination found no faults and no other source of the smell could be established. The aircraft continued to operate without further recurrence of this particular defect. Subsequently, this aircraft suffered another occurrence, whereby the cabin crew smelt an electrical burning smell around the area of the forward toilet. The flight crew made an examination of the area and found that the water heater was 'hotter than normal' and the Captain pulled both the water heater and toilet flush circuit breakers. The toilet compartment was monitored throughout the remainder of the flight during which time the smell dissipated. Engineers attended the aircraft at the end of the flight but no faults could be found with any of the systems in the area. It has been suggested that during heavy periods of rain, greasy deposits are often washed into the APU air intake so that, when the APU is started, these deposits are drawn through the compressor into the air conditioning system, which may result in oily smoke in the cabin. This phenomenon has been publicised to flight crew. No further reports have been received since, although the operator continues to monitor the situation. CAA Closure: The hazard is adequately controlled by the actions stated above.
8-May-2004	EMB145	200402882	Strong burning smell in cabin / 02 & goggles / cabin crew nauseous /no fault found / "considered that the odour was not originated within the aircraft" (not enough info to support this statement)

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23-May-2004	A319	200403186	Pretitle : Shortly after the air conditioning packs were selected ON, smoke was reported from the passenger cabin. MAYDAY declared, aircraft returned and landed safely. No fault found. Precis : NOT PROVIDED
23-May-2004	EMB145	200403310	Unpleasant smell (strong 'old sock' smell) through aircraft / hydraulic oil contamination of underfloor sound attenuating blanket / smell like that previously experienced due hydraulic fluid leakage
26-May-2004	BAe 146	200403375	Smoke in cockpit
7-Jun-2004	A320	200403624	AMS-LHR / BA441 / Pursar thought plane depress / 1 crew on 02 / symptoms / Capt said engine had been changed - nothing wrong.1 c/c got off. F/O said all weird. Hot - dehydr / purser nervy- Not ASR'd / MOR describes 'fuel like' fumes in rear cabin. Nr 2 pack selected off & fumes dissipated
8-Jun-2004	B757	200403723	Hot electrical fumes in cabin / PAN / diversion to LIS / engineering considered cause to be dust deposits in the filter to recirc fan / (unknown which filter & source of dust)
18-Jun-2004	B757	200404033	Burning smell throughout a/c / 02 by P2 / pax - panic / QRH for smoke, electrical smoke, fumes removal carried out / smoke remained / PAN
30-Jun-04	EMB145		Intermittent acrid smell in cockpit and subsequent diversion. Whilst in cruise at FL340 a peculiar smell became apparent. Intermittent for approx 5-10 mins and then disappeared for about 10 mins before re-occuring. Smell became more distinct than previously. PAN call made and decision to divert to Manchester. Cabin crew and Passangers briefed. Subsequent diversion uneventful. Unable to discover origin of smell in time available. On ground, source found to be flight guidance panel.
07-Jul-04	A321	200404523	G-OZBE. Malaga. Smoke in cockpit during descent. Extensive investigation found no faults; monitoring for three months and a supplementary report concluded that there had been no recurrence. At 5000ft during descent, visible thin smoke was seen in the cockpit, accompanied by a smell similar to electrical burning. A MAYDAY was declared and the flight crew donned oxygen masks. The smoke dissipated during short finals and the aircraft landed uneventfully with fire services in attendance, prior to being parked on a remote stand. At no time did smoke enter the cabin. Following engineering investigation, an engineer suspected the possible cause as smoke from nr1 engine bleed. Investigation, including visual checks of the avionic bays and flight deck circuit breaker panels were carried out. Engine runs carried out with engine bleeds and packs on and no smoke was apparent, although a smell of burning oil was reported from the nr1 engine at shutdown. Further troubleshooting was carried out but no firm cause was found. A supplementary report after three months concluded that there had been no other smoke related reports. CAA Closure: The hazard is adequately controlled by existing requirements, procedures and documentation
9-Jul-2004	B757		Oil fumes detected- see MOR 200405088
9-Jul-2004	B757		Oil fumes detected- see MOR 200405088

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9-Jul-2004	B757	200405088	During operator review, subject aircraft had reports of oil smell on preceding two flights. Investigation found oil levels above operator's limit.Oil levels serviced previous night
11-Jul-04	B757	200405089	Engine oil levels overfilled
16-Jul-2004	B757		G-EUPC / BA 972 / FCR / strong oily fumes / tech log entry only
20-Jul-2004	EMB145	200404928	Transient acrid smell on 2 take offs during gear retraction / no fault found (unknown if this was oil related as further details not available)
20-Jul-2004	EMB145	200406229	Smoke & fumes in pax cabin & f/deck believed to be from faulty APU / MEL raised to enable aircraft to operate without APU / APU remains concern at operator level (lavatory smoke detector can be activated following such smoke events)
21-Jul-2004	B757	200405128	Fumes in flight deck on take-off. Engine over serviced by 0.75 litres of oil
22-Jul-2004	B757		Fume event- G-BYAO
22-Jul-2004	B757		Fume event- G-BYAO
26-Jul-2004	BAe 146	200405021	Acrid fumes in cabin during & after turnaround / No fault found / APU selected off on ground
26-Jul-2004	B737	200405054	CAA Closure: The hazard is adequately controlled by existing requirements, procedures and documentation
31-Jul-2004	EMB145	200405244	Smoke & fumes in flight deck / 02 / no fault found after investigation occurred after crew verbal reports
2-Aug-2004		200405703	Strong plastic burning smell in cabin leading to eye irritation, headaches & nausea / all 3 cabin crew unable to continue duty / APU oil deprime valve failed which can allow oil into air supply if not working adequately - see MOR for further description of defect
3-Aug-2004	B757		Fume event- G-BYAO
3-Aug-2004	A320		ASR / G-BUSD / BA556 / LHR-FCO / Parked. Fumes on the ground needing jetty to be reattached to clear fumes. Fumes put down to "heavy rain/storm dislodging contaminants in APU/aircraft ducting".
4-Aug-2004	B757		Fume event- G-BYAO
5-Aug-2004	B757		Fume event- G-BYAO
9-Aug-2004	EMB145	200405613	Burning plastic smell in cabin reported by cabin crew & pax. Also evident in f/deck / no fault found
11-Aug-2004	B757		Fume event- G-BYAJ
11-Aug-2004	B757		Fume event- G-BYAO
13-Aug-2004	B757		Fume event- G-BYAO
13-Aug-2004	B757		Fume event- G-BYAJ
20-Aug-2004	B757		Fume event- G-BYAU
23-Aug-2004	A319		ASR / MOR / G-EUPP / BA970 / LHR-HAM Prior to boarding cabin crew reported smoke in the cabin. Crew also saw and smelled smoke in the cabin and ordered four cabin crew to carry out rapid precautionary disembarkation. APU shut down. Engineering said APU may have ingested a large amount of water from a heavy rain shower.

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23-Aug-2004	B757	200406121	G-CPER / ASR / MOR / LHR-LIN. Smoke on flight deck during pre-flight checks / QRH and precautionary evacuation of crew / AFS alerted.
26-Aug-2004	BAe 146	200405982	Fumes inside aircraft / PAN / 02 / All crew members unwell & hospitalized at SOU / possible hydraulic leak /
28-Aug-2004	B757		Fume event- G-BYAI
28-Aug-2004	B757		Fume event- G-BYAI
29-Aug-2004	B757		Fume event- G-BYAF
5-Sep-2004	B757	200406280	G-CPET / LHR-MAD / BA456 / ASR / MOR. Fumes on flight deck after take off / P1 donned 02 / P2 did not have time to don oxygen as flying. No fault found
10-Sep-2004	B757	200406679	ASR / MOR / G-CPEM / BA568 / LHR-LIN diverted to GVA Burning smell in f/deck & cabin whwn power applied during cruise in turbulence / PAN / Hydraulic reservoir found overfull
14-Sep-2004	A320	200406694	Aircraft returned due smoke in cockpit / MAYDAY
21-Sep-2004	B757		G-CPES / ASR / LHR-EDI / BA1444. Smell had cleared by flap retraction so no QRH / Oxygen was used.
27-Sep-2004	EMB145		Similar problem to same aircraft on 4/10/04 noted in tech log. No MOR raised
28-Sep-2004	B757		G-CPET / MAD-LHR / BA456 / ASR / MOR / Oxygen After landing strong fumes on flight deck after APU started. Fumes drill carried out and fumes cleared after approximately 3 minutes. Both pilots used oxygen to carry our QRH Symptoms experienced were irritation in throat and eyes, slight headache / light headedness. Engineer confirmed fumes were present on the flight deck.
30-Sep-2004	B777	200407073	Pretitle : Smoke on flight deck. MAYDAY declared and aircraft diverted to Manchester for overweight landing. Precis : Approaching top of climb, smoke appeared from vents. MAYDAY declared and flight crew donned masks. Diversion and emergency landing at Manchester. Split duct found in electrical and electronic bay sucking in dust. No smoke involved. Inquiries reveal that there have been a number of incidents in which the flight crew reported a smoke/haze/smell on the flight deck. This investigation includes MORs 200407073, 200407828,200502435 and 200504014. The Operator Engineering investigation while extensive was inconclusive - small amounts of surface dust were found within the area of the flight crew shoulder harness heater ducting on a number of aircraft inspected during this fleet-wide campaign. However, the amount of dust found was not considered to be unusual or abnormal. CAA Closure: The hazard is acceptable provided the frequency remains low.
4-Oct-2004	EMB145	200407138	Fumes and grey / haze mist in cabin reported by cabin crew & Pax / PAN / 02 / Precautionary medical checks for crew / Gasper fan inlet completely blocked by debris with fan inlet screen heavily contaminated considered to result in fan overheat & fumes
4-Oct-2004	B757	200406978	Fumes in in flight deck after landing /smoke hoods donned by both pilots
8-Oct-2004	B757	200407359	G-CPEM / ASR / MOR / ABZ-LHR / BA1301 / Non visible fumes on flight deck on take off & initial climb for about 2 minutes / P1 donned 02 as slightly dizzy even though fumes were thought to be 'mild' / P2 elected not to use 02 as no adverse symptoms.

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11-Oct-2004	EMB145	200407361	CC / Flight Deck air cond. smell. At various stages in today's 4 sector programme we noticed a smell of dirty air (oily) or "sweaty sock" smell on the flight deck. We carried out the 4 sectors whilst trying to isolate the source which was traced, we think, to Bleed #01. Engineers informed and bleeds isolated. Crew initially felt light-headed but symptoms quickly died out when bleed isolated. Air Quality Forms filled in and attached. Aircraft Tech Log entry carried out and left with Engineering staff in LBA.
16-Oct-2004	B757	200407467	Burning smell in rear galley could not be identified / no faults found (engineers found 1 oven charred internally but unknown if this was sole fault)
17-Oct-2004	B757	200407488	G-BPEK / ASR / MOR / BA854 / LHR-PRG. Oil fumes on take off & initial climb to 5000 feet / O2 / investigation processed under MOR on incident on same aircraft 27/7/03 No fault found. Aircraft released for further service.
19-Oct-2004	B757	200407588	Pretitle : Oil fumes apparent on flight deck during take off roll, clearing by 6000ft. Crew oxygen masks used as per QRH. Precis : See also 200306174. Investigation being progressed under 200306630.
19-Oct-2004	B757	200407536	G-CPER ….SEE BA1444 REFERENCE IN NEXT SECTOR RE FUMES.
19-Oct-2004	B757	200407536	G-CPER / ASR / MOR / LHR-EDI / BA1444 / 02 / Burning smell in flight deck attributed to oil leak in climb to 6000 feet. Same had occurred on previous sector but engineering had declared aircraft as servicable and despatched into service. Second time round engine changed (thorough engineering incl boroscope found leak)
20-Oct-2004	BAe 146	200407632	Yellow hydraulic system problem with burning smell in cabin
21-Oct-2004	BAe 146	200409537	G-JEBD. Fumes on 2nd sector with 2 cabin crew on 02 as dizzy & light headed. Aircraft continued to operate with P1 dizzy & tingling in legs on 4th sector /nothing entered in tech log / ASR & air quality report to be filed /
22-Oct-2004	B757		Fume event G-BYAY
23-Oct-2004	B757		Fume event G-BYAY
23-Oct-2004	B757		Fume event G-BYAY
23-Oct-2004	B757		G-CPEN / BA 852 / oil fumes / ASR / MOR
23-Oct-2004	B757	200407711	G-CPEO / ASR / MOR / LHR-WAW. Contaminated air on flight deck until climb power selected. Fumes cleared & therefore oxygen not used
26-Oct-2004	B757	200407753	Turbulence led to altitude deviation followed by acrid fumes throughout aircraft / no fault found
26-Oct-2004	B777	200407828	Pretitle : Strong smell of smoke on flight deck during approach. Crew donned oxygen masks. Precis : On intermediate approach, a strong burning smell was evident on the flight deck. The flight crew donned oxygen masks and after approx 1 to 2 minutes the smell dissipated. Only a faint burning smell was detected in the passenger cabin by row 1. The source or type of burning smell was unable to be identified. Extensive Operator investigation was inconclusive but small amounts of surface dust were found within the area of the flight crew shoulder harness heater ducting on a number of aircraft inspected during this fleet wide campaign. However, the amount of dust found was not considered to be unusual or abnormal. CAA Closure: The hazard is acceptable provided the frequency remains low.

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29-Oct-2004	B757		Fume event G-BYAS
29-Oct-2004	B757		Fume event G-CDUP
30-Oct-2004	B757		Fume event G-CDUO
31-Oct-2004	B757		Fume event G-BYAT
31-Oct-2004	B757		Fume event G-BYAT - car crash /off 14 months
2-Nov-2004	A320	200408098	G-BUSH / ASR / MOR / BA766 / LHR-OSL / Oil smell on f/deck after t/off, and during climb to 12000ft / fumes not considered intense enough to warrant use of oxygen / ASR / see event same day below /
2-Nov-2004	A320	200407985	G-BUSH / ASR / MOR BA706 / LHR-VIE / Fumes on previous sector- engineers signed off as 'report further' / fumes again same day / Strong musty oil fumes gave P1 immediate intense headache and crew were hospitalized in Vienna (MOR lists only oil fumes, 02 & no fault found) CAA fails to list reference to medical status & hospitalized / med tests done were ECG, chest X-ray, blood test -refer MOR 200408098 Event was traced to the APU which was scheduled to be replaced.
2-Nov-2004	B747	200407984	Fumes / suspected contaminated air on flight deck and in passenger cabin / aircraft diverted, dumped fuel / 02 / 4 passengers hospitalized as a precaution / recirc fan failure / treated as contaminated air incident / see also 200408466 and 200409003.caa closure: investigation progressed under MOR 200400447
3-Nov-2004	B757	200408064	ASR / MOR / P1&2 effected- throat irritation, light headed & sore eyes & oily taste in mouth / holed air con duct / engine overfilling ?? / fumes reoccurred on 4 Nov 04. Inspection maint done 8/11/04. Fumes again 16/11/04. P1 still had symptoms next day & skin problems & health problems since
4-Nov-2004	B757		Data from 3/11/04 incident - not on CAA database
4-Nov-2004	A319		BA 641 (G-EUUJ) / Oil smells On Flight deck on this & previous t/off
11-Nov-2004	BAe 146		8736 / G-CFAH / LCY-FRA / strong contaminated air smell on flight deck (smelly socks) on T/O changeover of air -refer 3 7 4 July, 2005
11-Nov-2004	A319		G-EUPZ / LHR-ZHR / diverted to LGW / AAIB / MOR / Not on CAA MOR database During climb from LHR at 5000 feet a 'woody' burning smell filled the flight deck. Flight deck fumes continued. First Officer put on oxygen. At 22000 feet 'Mayday' declared. Both pilots then used oxygen and diverted to LGW. Pax in 1A having problems breathing and was put on oxygen. No fault found.
11-Nov-2004	BAe 146	200408213	G-CFAH / LCY-FRA / strong smell of contaminated air on f/deck on t/o & air changeover / ASR / manuf put a/c on 'systems integrity log' for monitoring

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12-Nov-2004	A320	200408204	G-BUSF / BA1442 / LHR-EDI return to LHR / Oily fumes in f/deck / 02 / PAN / MOR / AAIB provided CAA with initial notification / Aircraft had history of smoke / fumes on previous 2 sectors in tech log with engineers requesting new crew to report further / engine recently changed / tasted & smelt oil fumes / pax reported fumes in cabin / P1-light headed, dry mouth, tired, tightening around eyes & felt pressure to continue duty / P1 requested blood tests from BAHS but advised not possible & A&E also unlikely to do these / requested BAHS Dr to follow up & advised that blood test n/avail as no base line done & exposed to too lower concentrations.
12-Nov-2004	B757	200408265	G-BPEE / ASR / MOR / AAIB / NCE-LHR / Repeated short sharp bursts of contaminated air smelt by pilots- cc- pax / flight ops advised to operate return sector / crew unaware of level of contamination with capt 'feeling spacey' / 02 / PAN / crew effects (capt unwell 3 days later) / fumes smelt by fire services / APU area found to be oily but no leaks found - fire chief said 3rd aircraft that day with fumes
14-Nov-2004	BAe 146		G-JEBG / Techlog No 668487: Smell of fumes of short duration during various phases of flight over 4 sectors. Never of long enough duration to pin point or identify the source. Last sector into BHD strong smell of fumes on approach during landing checks on swap over from engine air to APU air, and taxi in on to stand / ASR and Air Quality filed / Cabin crew smell fumes in rear galley on second sector / Symptoms were Head Ache, Tiredness, Irritation of Eyes and Throat. Weezing chest and Coughing the next day.
15-Nov-2004	B757	200408292	G-CPER / LHR-WAW / BA846 / ASR / MOR / 02 / Burnt oil fumes noticed by both pilots & 1 cabin crew on take off, climb / Right pack made INOP / fumes noticed again on return sector…..
15-Nov-2004	B757	200408292	G-CPER / WAW-LHR / BA847 / ASR / MOR / 02 / After flap retraction flight crew donned oxygen and actioned QRH memory items, due oil smell. Fumes smelt in cabin by crew. Engineering unable to fault on the ground
15-Nov-2004	BAe 146	200408352	Fumes in cabin / gearbox leaking / all cabin crew advised light headed in crz / attended medical centre /Operator considering using a cabin air monitoring unit for future events
16-Nov-2004	B757	200408448	AAIB provided CAA with initial notification / G-GPEE - BA776 / ASR / MOR / AAIB (same incident as 12/11/04) First flight after 12 Nov 2004 incident / fumes present / 02 / oil like fumes returned / P2 had "buzzy head and body". P1 felt "slightly spaced" and found it an 'effort to concentrate' / All crew saw paramedics & doctor in Stockholm reporting 'headaches, a sore throat-coughing- nausea- burning sensation in the lungs, tightness in chest - and a "slightly spaced" feeling' , difficulty in concentrating / given all clear to ferry a/c to LHR / swabs taken from right engine compressor identified Exxon Mobil Jet Oil II / see MOR 12 Nov, 2 Mar, 29 Feb 2004 all same aircraft .see 23 Nov, 2004
16-Nov-2004	B757		Data from 3/11/04 incident - not on CAA database
21-Nov-2004	B757		sweaty socks smell when anti ice selected in descent / Had fumes incident also in Oct 2004
21-Nov-2004	EMB145		AAIB provided CAA with initial notification / fumes in cabin due failed air cycle machine / 02
23-Nov-2004	B757		G-GPEE / AAIB (same incident as 12/11/04). Fumes smelt throughout flight.

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29-Nov-2004	A321	200408647	Pretitle : Oily fumes on flight deck and in cabin after take-off. PAN declared. Aircraft returned. Recurring problem. Precis : Almost immediately after the APU bleed was selected 'off' during climb out, a strong oily smell was evident on the flight deck and in the passenger cabin. Shortly afterwards the fumes appeared to dissipate but then re-appeared on the flight deck and in the passenger cabin. The aircraft levelled at FL210 and a PAN was declared for a return to the point of departure. Descent was initiated and fume removal drills were actioned. At FL100 with air conditioning packs 'off', the fumes completely cleared. An uneventful overweight landing at 77.7 tonnes was carried out. Similar noxious fumes were evident throughout the aircraft whenever power was applied during taxi out for a flight earlier the same day. Investigation found that the Operator had asked their nominated engineering overhaul organisation to carry out engine compressor washes, which it turns out were not completed properly. The bleed had not been isolated and residual cleaning materials required a longer than normal idle run to burn them off. The source of the oily fumes was not directly related to engine malfunction. Procedures have been altered and all parties involved were briefed of the outcome of this investigation. CAA Closure: The hazard is adequately controlled by the actions stated above.
5-Dec-2004	Dash 8	200408810	Pretitle : Fumes in cabin on pushback. / Precis : Shortly after pushback, with bleed air 1 and 2 on and wind at right angles to the aircraft, the nr1 cabin attendant reported that it was hot in the cabin. The duct temperatures were checked and were high but not excessive (in the green arc, with no associated cautions). There were no visible fumes in the flight deck. Initially the bleeds were switched off but the smell wasn't clearing in the cabin and the nr1 reported that the burning smell remained. The bleeds were then selected on at minimum temperature, max rate to try and clear any residual smell (the duct temps were checked to be low). The nr1 reported that both herself and the nr3 felt unwell and unfit to operate so a request was made to taxi to an available stand. The nr3 went onto oxygen. Engineers attended the aircraft, while the cabin crew went to hospital for a check up. The flight crew reported no ill effects as the fumes seemed to have been contained in the cabin. Engineering investigation failed to reveal any fault with no smells or contamination found. The operator considers the most likely cause was contamination from an external source, such as a fuel bowser, a truck or aircraft exhaust gases, being drawn into the aircraft Environmental Control System. Investigation, including engine ground runs found no abnormal smells or contamination. Nil related defects occurring to date. Probable cause considered as external contamination at BHX - exhaust fumes from passing motor vehicle or another aircraft being drawn into aircraft ECS. CAA Closure: The hazard is adequately controlled by existing requirements, procedures and documentation.
7-Dec-2004	B744		VS5 / ASR / Fume filled cabin, dumped fuel and diverted into Shannon.

7-Dec-2004	A320	200408854	G-MIDZ. Enroute. Engine stall followed by sweet burning oil smell which dissipated after 10mins, however QRH smoke drill not actioned. Nr2 engine stall and associated ECAM caution at top of descent. PAN declared. Investigation found this event was caused by a combination of compressor blade wear and latent FOD. As thrust was reduced to idle at top of descent, two loud thuds were heard in rapid succession followed by a sweet burning smell on the flight deck and in the forward cabin. The engine stall QRH drill was completed and engine parameters remained normal with slightly elevated EGT +30deg. A PAN was declared and the cabin crew briefed for "a precautionary landing" at destination airfield. Autothrust was disconnected to ensure smooth and gradual thrust changes. The smell of burnt oil dissipated completely after 10 minutes and the QRH smoke drill was reviewed but not actioned. Investigation revealed that this event was caused by fracture of an HIP stage 3 blade caused by 'clapper' wear in conjunction with FOD or a bird strike which may have been ingested sometime previously. Such events can be made worse by worn clappers and certain types of wear patterns. This type of event was previously known and 2 NMSBs were issued by the OEM, however reports were specific to Far East operators and directed at them. Just prior to this operator's first event, the OEM issued SIL 213 following reports of HPC stage 3 blades experienced by American and European operators. An inspection ER was raised to check for clapper wear on all engines with reported bird strikes in 2004. In addition, borescope training has been carried out to alert Engineers to the correct procedure for checking clapper wear. For engines exceeding 5000 cycles, scheduled borescope inspections will be carried out every 750 cycles. Also, a redesigned HPC stage 3 blade has been developed and these will be installed on the relevant operator engines at the next shop visit. CAA Closure: The hazard is adequately controlled by the actions stated above.
8-Dec-2004	BAe 146	200408975	Flight crew incapacitation due to possible air quality problem: P2 felt unwell (faint & breathless with shaking hands) / 02 given / P1 had headache with flu symptoms and was in a state of euphoria although successfully landed the aircraft while operating as single crew. P2 sent to hospital & P1 suffered headache & flu symptoms for 24hrs. Incident not entered in aircraft tech log. APU exhaust may have entered air supply. Subsequent investigation found APU Bay covered in Soot as were packs and ducting.
9-Dec-2004	B767		Transient fumes
9-Dec-2004	B757		FCR / G-BPEE / BA777 / (refer AAIB report of 12/11/04) metallic hot oil odour after start / crz. Also smelt by cabin crew on previous sector / No definitive cause
12-Dec-2004	B767		Oil fumes
12-Dec-2004	EMB145	200409034	Burning smell on flight deck during 1st flt after engine change. Fumes attributed to 'normal disturbance / contamination of the air systems after engine change

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12-Dec-2004	B757		ASR / G-CPEN / BA 936 / LHR-DUS. Oil smell- noxious fumes on take off - climb for short time - therefore 02 not used (MOR not ticked)
15-Dec-2004	B757		ASR / BA855 / G-CPEO / LHR-PRG…SEE ENTRY ON RETURN SECTOR BELOW RE FUMES
15-Dec-2004	B757		ASR / BA855 / G-CPEO / PRG-LHR. Fumes after start / taxi . Smelt on 2 previous sectors also / No. 1 engine using more oil
16-Dec-2004	B757	200409538	BA1434 / LHR-EDI / G-CPET / ASR / O2 / During the take off roll and initial climb strong fumes were detected in the flight deck. The fumes smelled oily initially the then became chemically in smell. Oxygen masks were put on and the departure continued. Masks removed when smelld thought to have cleared. On landing the return flight was cancelled but later engineering asked if crew would fly aircarft back to London minus passengers. Captain not happy to return to LHR but accepted to ferry aircraft with cabin crew only / see tech log. See next sector information same day below.....
16-Dec-2004	B757		EDI-LHR / G-CPET / ASR ....Follow on from previous sector: CSD and 1 cabin crew sat in flight deck for take off as empty sector. On take off they smelt what was described as "oily dirty socks". Just after that the crew seated near door 1 came up and said they could smell the same thing in the cabin. Captain and First Officer could also smell contaminated air. On landing all crew went to DOM and relay manager and spoke of their concerns about what they had breathed in.
17-Dec-2004	A319		G-EUPL / LHR-GVA / BA 734 / Oily fumes / burning smell on base leg to runway 23 over high terrain just before intercepting the localiser. Fumes present for 2 to 3 minutes / About to use O2 when fumes appeared to clear. Also noticed on initial taxi in.
17-Dec-2004	A319		ASR / MOR / G-EUPL / GVA-LHR / BA 735 / Oily fumes just prior to joining the hold at 'Biggin Hill' / Oxygen used and PAN declared / Aircraft given straight in approach / Cabin crew said no fumes present in the cabin / No fumes present after landing. Two days later Captain had swollen lymph glands in his neck which lasted a couple of days. His doctor said thiese could be due to a throat infection or from inhaling the fumes. No fault found
19-Dec-2004	A319		BA314 (G-EUPO) / Perceptible oil smell in flight deck on climb & approach / FCR only / oxygen not used
19-Dec-2004	A319		BA319 (G-EUPO) / Perceptible oil smell in flight deck / oxygen not used
20-Dec-2004	B757		G-BPEE / oil vapour fumes detected in conditioned air to flight deck last two sectors
22-Dec-2004	BAe 146	200409300	Contaminated cabin air reported by cabin crew on landing. All crew including flight crew reported headaches & stinging eyes
22-Dec-2004	B737	200409272	Smell of smoke in rear galley during approach. Smell persisted and galley power turned off. Fire services inspected aircraft when on apron, with nothing immediately found. / Initially not on CAA database- refer MOR 200500843
27-Dec-2004	B757	200409311	Smoke haze in passenger cabin / No fault found. Said to be possibly of electrical origin but no evidence to support this / no fault found
30-Dec-2004	EMB145		CC / Slight chemical smell on take-off. Normal chemical smell of a/c which has not been used overnight came through pack on take-off. Both pilots observed they had dry eyes. Note : Captain never has dry eyes. Suspect possible contamination in pack.

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1-Jan-2005	A319	200500067	LHR / Pretitle : Smoke and strong burning smell in cabin. Unable to reproduce on the ground. Precis : After doors closed, the purser called the flight deck to report smoke in the cabin. On opening the flight deck door, greyish smoke was observed throughout the cabin and a burning smell was apparent. When the bleeds were switched off the smell cleared but returned when the bleeds were switched back on, remaining until the forward door was opened. The dispatcher was asked to bring the jetty back and an engineer attended to assess the situation. As a result, it was decided to transfer to another aircraft and the passengers were disembarked accordingly. With only elect power there was no smell or smoke over a 1.5 hour period. The LH pack only was run from APU for 15 mins but there was no smell or smoke. The same was done for the RH, again, no smell or smoke. No CFDS fault messages or C/Bs popped. All galley ovens tested, no smell or smoke. Suspect origin of smell from APU air delivered after a heavy rain shower acting like a compressor wash on APU and thus giving a brief strong smell through the packs which eventually purged off. CAA Closure: The hazard is adequately controlled by the actions stated above.
2-Jan-2005	B757	200500013	LH engine oil level above company limits.
4-Jan-2005	A320		ASR / G-EUUN / BA1398 / LHR-STR / Parked. Fumes on the ground throughout aircraft aircraft as seen as a light haze. Engineer confirmed oily smell and suspected oil in APU ducts. Aircraft cahnged although engineering were unable to identify source of the fumes.
14-Jan-2005	B757	200500321	Engine oil level above company limits
16-Jan-2005	EMB145	200500287	Very strong fuel smell on past start checks & taxi out, return to stand / All crew members felt light-headed with slight headaches / flight continued 2 hours later after engineering had traced the problem to the nr1 engine. It was suspected that the injectors were "carboned" so flight was authorised with Pack 1 off. All crew members felt OK after 30 minutes and were ready to continue after satisfactory engine runs. Investigation being progressed under 200407361.
16-Jan-2005	B757		G-GPEE / AAIB (same incident as 12/11/04)
18-Jan-2005	B757	200500474	LH engine oil level found above company limits / During the Powerplant weekly review of cabin odour events a report of a very slight oil smell during taxi out was noted. The LH engine oil level was checked and found to be 1 litre above the company limits
19-Jan-2005	EMB145	200500426	Strong smell of contaminated air from APU each time APU used on 2 sectors / APU reduction gearbox vent pipe kinked (co report- ASR / G-EMBF/ BA1840 / On arrival at the aircraft the crew noticed that there was strong unpleasant smell emanating from the air conditioning system, in which the air supplied to Pack 2 was sourced from the APU. When Pack 2 was turned off, the smell slowly cleared and APU air was not used again until immediately prior to the following sector, operated by the same flight crew, at which time a similar smell recurred / Engineering subsequently found the APU reduction gearbox vent pipe found kinked / low risk)
28-Jan-2005	BAE 146		G-JEBD / BHD-BHX / BE 413 / Severley Bad Burnt Rubber smell with APU Air on. APU air switched off for rest of flight. No further smells. Cabin Crew feeling Dizzy and Nauseous on arrival.
30-Jan-2005	A319		G-EUPC / BA455 / FCR / sweet oil smell on start up / descent / FCR / tech log
1-Feb-2005	A320		Smelt fumes on several flts

5-Feb-2005	B737	200500843	Burning smell in cabin caused cabin crew eye and throat irritation / Mayday / air conditioning fault suspected / irritation to throat & eyes of cabin crew / aircraft had history of similar occurrences / see 200409272 (not on CAA database)
8-Feb-2005	B757	200501101	G-BPEK / ASR / MOR / BA344 / LHR-NCE / Acrid fumes in flight eck & cabin in climb / P2 used 02 until top of climb / fumes & smoke checklist not actioned as transitory / G-CPEK -see 20407488, 200305002
8-Feb-2005	A319	200500872	G-EUPM / BA925 / FCR / ASR / MOR / CGN-LHR / Oil throughout flt / P1 & P2 light-headed / 02 / Emergency PAN & priority ldg. / Capt, P2 & CSD went to BAHS (British Airways Health Services) / major oil leak from the APU CAA Pretitle : PAN declared due to oily smell on the flight deck. Masks donned by crew. Uneventful landing carried out. APU removed - no fault found. CAA Precis : The APU was removed and sent to the manufacturer (Honeywell, Luton) for investigation. Initial inspection showed that the APU inlet was contaminated with a clear fluid with small amounts of hydraulic fluid and black oil. The APU was borescoped to detect any internal oil leaks. There were no oil leaks found, however, the compressors were both wet again with a clear fluid. The APU bleed was clean. A partial strip of the APU was carried out to remove all traces of contaminates. The APU was put onto the test-bed and run several times with bleeds on. A black light was used to find traces of oil in the bleed, none was found. No new contamination was found during post test inspection. From the workshop input, there appears to be no evidence that the APU was the source for the smoke in cabin event. The APU appears to have ingested either de-icing fluid or hydraulic fluid whilst providing air to the cabin. The APU was returned to the operator for further service. CAA Closure: The hazard is adequately controlled by the action stated above.
9-Feb-2005	A320	200501008	ASR / MOR / G-BUSF / LHR-MAN / BA1398 / All crew members smelt cheesy / chemical smell on & off. Small piece of plastic in inlet to core of engine / (unknown if this was sole source / further info req) CAA Pretitle : Unusual smell in passenger cabin and on flight deck. CAA Precis : All crew members became aware of a "cheesy/chemical" smell inside the aircraft on departure. The smell dissipated after 3 or 4 minutes, reappeared at 10000ft in descent and dissipated again by 4000ft. A full engineering inspection was carried out, during which a small piece of plastic was found in the inlet to the nr2 engine core. Air conditioning packs were run via the APU bleed on the ground with no fault found and the aircraft departed for the return sector with the APU feeding both packs. In the cruise at FL150 and 280kts, fault finding with packs and bleeds could not reproduce any smells and the flight continued without further incident.

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10-Feb-2005	Q400	200500951	G-JEDP / GLA-BHX / BE 829G. Fumes & smoke / evacuation / GLA. Abandoned Take Off Due Engine problem. On returning to Stand Flight Deck and Cabin filled with Smoke. CAA Pretitle : Following an abandoned take off and subsequent taxi, aircraft was shut down due to smoke in the cabin. AGI initiated. Passengers disembarked on taxiway. AAIB AARF investigation. CAA Precis : AAIB Bulletin 11/2005, ref: EW/G2005/20/05 - Summary: As the aircraft commenced its take off run, the take off warning horn sounded. The take off was rejected, but while taxiing for another attempt, the pilots noticed a burning smell on the flight deck. When advised by the cabin crew that there was also a smell of burning and some smoke in the cabin, the commander stopped the aircraft on the taxiway and initiated an expeditious disembarkation using the forward passenger door only. An engineering investigation carried out by the operator's maintenance personnel and the engine manufacturer found that a piece of the right hand engine compressor inner support had become detached, causing damage to a compressor oil seal and allowing oil to contaminate the engine bleed air. The engine manufacturer is aware of the issues and is addressing them through component re-design and engine modifications. CAA Closure: The hazard is adequately controlled by the actions stated above.
11-Feb-2005	Q400		G-JEDP / SOU-GLA / BE884. After Landing, cabin crew reported that they had bad headaches and that there had been an unusual smell in the cabin. After a few minutes the No 1 Vomited. Smell occurred during descent. Both pilots smelt something but were unaffected. Crew from previous day had had problems with fumes on this aircraft.
14-Feb-2005	A319	200501099	G-EUOH / LHR / APU manually shut down due to EGT near to exceedance (980 deg) and strong burning smell throughout cabin. Passengers not boarded. Fire services attended. Aircraft despatched with no APU. Investigation traced the problem to an unserviceable starter motor. The starter motor was replaced and there have not been any further reports of cabin/flight deck odours reported since. APU starter motor reliability is of concern and currently an upgrade programme is underway. This starter motor will be tracked down and reviewed to determine if the failure is captured by the modification programme. CAA Closure: The hazard is adequately controlled by the actions stated above.
15-Feb-2005	EMB145	200501351	G-CCYH / EDI. Smell of oil. Investigation, including borescope inspections, resulted in nr2 engine being replaced. Strong smell of oil in cabin and flight deck during initial climb and approach. Member of cabin crew reported mild headache and nausea. Aircraft subsequently operated with Pack 2 inoperative. No further occurrence. Initially, this was thought to have been an artefact of a recent nr2 engine change. However, further investigation, including borescope inspections, resulted in nr2 engine being replaced after 42 flying hours. Strip report confirmed that the engine front frame was suspect and had been replaced. CAA Closure: The hazard is adequately controlled by the actions stated above.
16-Feb-2005	Dash 8		ASR -55/05/DH8 -activation of toilet smoke detector -see incident 25/3/05 - oil contamination of air conditioning system
16-Feb-2005	Dash8		ASR -56/05/DH8 -activation of toilet smoke detector -see incident 25/3/05 - oil contamination of air conditioning system
17-Feb-2005	B757	200501107	Engine oil levels above company limits / Initially not on CAA database- refer MOR 200507833 / See also 200405088, 200405089, 200405128, 200500013, 200500321 and 200500474 (not on latest database 14/10/05 or previous)

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18-Feb-2005	EMB145	200501351	Strong fumes in cabin & f/deck. 1 cabin crew reports headache & nausea. MEL to operate pack 2 off
22-Feb-2005	BAe 146		G-JEBD / LGW-BHD / BE974. Due to "extreme tiredness" Captain miss set ASI Bugs for landing by +10 knots. 13 ppms recorded on CO Monitor that sector.
23-Feb-2005	A320	200501332	CAA Pretitle : Significant fumes/smell/mist in rear cabin. MAYDAY declared. Aircraft returned. It is suspected that residual de-icing fluid accumulated in the APU duct after the previous LGW departure. CAA Precis : During initial climb (shortly after TOGA take-off in heavy rain), a significant "mist" with an "acrid" burning smell (affecting mouth and throat) was reported in the rear galley area. A decision was made to return and a MAYDAY was declared. During radar vectored downwind leg at 3000ft, lightning disabled the approach radar resulting in an ATC instruction to climb to 5000ft direct to TFS VOR for a full procedural VOR/ILS approach to R/W 26. The approach was flown with the air conditioning packs off (fumes dissipated) and an uneventful overweight landing at 69500kg was carried out followed by completion of the overweight QRH drill. Investigation found no defects on the bleed and conditioning systems. An engine run was performed by the crew with no findings. No reccurrence of ice ingested into APU bleed system. NOTE: QRH warns of this problem after de-icing but not on subsequent sectors; ice normally clears quickly with deselection of APU bleed. Event highlighted in Flight Deck newsletter. CAA Closure: The hazard is adequately controlled by the actions stated above.
28-Feb-2005	A319		G-EUPC / BA572 / LHR-MXP / ASR / Aircraft had been fully de-iced at base. APU was started and the aircraft filld with blue haze / smoke and strong acrid fumes. As a precaution crew were disembarked. No pax onboard at that time. APU Purged
1-Mar-2005	B737	200501566	EI-???? / STN / B737-800 / MAYDAY declared due to smoke in flight deck and cabin. Aircraft returned to departure airport where it landed with emergency services in attendance. Faulty environmental control system ECU; replaced. Investigation confirmed the fault lay with the environmental control system ECU, which was replaced. No further occurrences reported and no reliability issues with this component. CAA Closure: The hazard is acceptable provided the frequency remains low.
10-Mar-2005	BAe 146	200501713	Slight oil fumes on taxi out which increased throughout flight / flight crew sent to hospital / no fault found / possible temp control valve problem as fumes reported 5 days later but CAA data does not provide full details & ongoing history. 60 ppms recorded on CO Monitor on last sector.
14-Mar-2005	BAe 146		G-JEBD / BHD-BHX / BE 401. Fumes and Haze in flight deck and cabin due to APU Air being used after wings and tail had been de-iced

15-Mar-2005	B757	200501820	G-BIKF. East Midlands. Oil fumes on engine start, taxi & climb leading to sore throats, stinging eyes / aircraft returned to departure point / 02 not used /no single defect found capable of producing fumes. Oil fumes on flight deck. Aircraft returned. Overfill of the oil system or long periods of idle power settings may cause such events. Slight oil fumes were noticed during engine start, which failed to clear during the taxi out. The fumes were still evident during the climb and were now causing sore throats and stinging eyes. ATC were informed and a return to East Midlands initiated at FL230. No emergency was declared but ATC provided expeditious handling. QRH 'SMOKE OR FUMES AIR CONDITIONING' was actioned but to no avail although the fume intensity reduced noticeably when thrust was reduced for the descent. The flight crew elected not to don oxygen masks or smoke goggles but on reflection considered it would have been more sensible to have done so. The fumes persisted until the engine bleeds and packs were switched off when the APU was available during the taxi in. Subsequent strip examination of the engine failed to identify any single defect considered to have been capable of causing the reported fumes. Strip examination failed to find any single defect that could have caused the fumes, however there was oil present in the IP Compressor module. The overhauler has suggested an overfill of the oil system or long periods of idle power settings could cause such events. The operator has instigated a technical notice to control these situations and no further reports have been received. When the engine is returned to service active monitoring will be actioned. CAA Closure: The hazard is adequately controlled by the actions stated above
15-Mar-2005	A319		G-EUOF / FCR / BA963 / Oil smell on climb & descent
17-Mar-2005	A319		G-EUPO / ASR / MOR / DUS-LHR / BA941. A strong oil smell observed from take off power set to 10,000 feet (5 minutes). This was noticed only on the flight deck. Smell dissipated therefore oxygen masks not donned. Transient smell noticed in descent.
17-Mar-2005	B747	200501897	CAA Pretitle : PAN declared due to smell of oil in passenger cabin. CAA Precis : At the top of descent, following a turbulence encounter, oil was smelt in the cabin around seat 47B. The oil smell was identified as coming from the air conditioning system and the relevant QRH smoke drill was actioned. The smell reduced with the recirculation fans and Pack 2 OFF. The pilots donned oxygen masks as a precaution and a normal landing was carried out. A subsequent inspection of the cabin confirmed that just a slight oily smell remained.
22-Mar-2005	DHC8	?	Contaminated Air. See 04 April 2006. CAA Ref: 200502402
24-Mar-2005	EMB145	200502225	CAA Pretitle : Solvent smell on flight deck. CAA Precis : A strong smell of solvent was evident on the flight deck when the air conditioning packs were first selected on. The smell then dissipated but returned with any aircraft attitude change or turn, both in flight and on the ground.

25-Mar-2005	Dash 8		G-BRYV / BA1860 / ASR / Following earlier reports of a visible mist and oil smell in cabin and operating under ADDP103, with No.2 pack disabled, due to a suspected internal oil leak in No.2 ACM, cabin crew and pax again complained of mist in the pax cabin. ACM pack 2 P/N 782790-19 was replaced and ADD P103 cleared. For two related events nine days earlier see 55/05/DH8 and 56/05/DH8, which both resulted in a brief activation of the toilet smoke detector and engineering inspections found no fault. Engineering advise that strip report confirmed an internal leak of the ACM and suspect that the event recorded here was as a result of residual oil contamination within the air conditioning system. 'ASR / low risk'
30-Mar-2005	A319		ASR / MOR / strong chemical smell
1-Apr-2005	B777		G-ZZZC / BA225 / faint smell of fuel increased till could taste odour/ cabin crew member confirmed strong odour in f/deck. P1 reported slightly light headed, bad taste, & headache. Pax in seat 2E commented / ASR / several cabin crew reported symptoms headache & nausea / pax held on aircraft 7 hours while alternate a/c found
2-Apr-2005	B757		G-CPES / ASR / LIS-LHR / BA 497 / During pre-flight preperation with door 1L on airbridge, a notable 'oily/burnt' smell with 'moderate' blue colored haze became detectable in the flight deck and forward cabin area. Flight crew turned both packs off then later OK.
2-Apr-2005	Dash 8 Q400		G-JEDO / JER-LGW-JER / BE 940 / Acrid smell from fwd cabin air vent. Return to JER with non normal situation. Emergency "Local Standby" PAX Disembarked and aircraft left with engineers to establish a source of problem. Once in crew room, cabin crew felt sick, dispatched to Hospital for check up. CABIN SERVICES RESPONSE: Both crew members attended Hospital where blood tests were completed. The test results were negative. Doctor advised both crew tokeep an eye on any sign of contamination and gave them a check list to follow. Both crew declared themselves fit to operate the next day with no further problems reported.
3-Apr-2005	B757		G-CPEO / BA1439 / EDI-LHR / ASR / Fumes ? / Engineering carried out high power ground runs but no fault found.
4-Apr-2005	DHC8	200502402	CAA Pretitle : Oil smell in cockpit and cabin. Oil contamination within the air conditioning system contributed to this event. CAA Precis : Shortly after take off, oil fumes were noted in the flight deck and cabin, which were sufficient to briefly trigger the toilet compartment smoke alarm. After the 'Flt Compartment Duct Overheat' caption activated, use of air conditioning controls cleared the fumes before the QRH could be actioned. The reporter notes a similar fault occurred on the 22nd March, while it was noted the aircraft had a "fumey smell" before departure and after shutdown with cabin crew reporting a haze in the cabin on the previous three sectors. Inquiries revealed that nr2 air cycle machine had been replaced two weeks earlier. Investigation, including a strip report from the component vendor confirmed an oil leak on the compressor side of the ACM. It is suspected that residual oil contamination within the air conditioning system caused this event. CAA Closure: The hazard is adequately controlled by the actions stated above

4-Apr-2005	BAe 146		BA 1862 / ASR / G-BRYV / Passing 750 ft aal in daylight, a CAP 'FLT COMP DUCT HOT' caution occurred with abnormal 'oily' fumes evident in the Flight Deck and pax cabin, sufficient to activate the toilet smoke detector/ fumes disipated / Reporter notes an abnormal smell prior to and after arrival of this sector and 'haze' reported by cabin crew during the three previous sectors / similar fault on this aircraft recorded under an ADD thirteen days earlier and cleared three days prior to this event / unable to replicate fault during ground runs / Engineering advise that following a previous incident of fumes on this aircraft, see 55/05/DH8, 56/05/DH8 and 67/05/DH8, the ACM was replaced and strip report confirmed an internal oil leak / Engineering Review, considering the event recorded here to be as a result of residual oil contamination within the air conditioning system, intends no general safety response action / medium risk
4-Apr-2005	B777	200502435	CAA Pretitle : Dusty/damp haze on flight deck. Flight crew oxygen mask donned. Investigation thorough but inconclusive. CAA Precis : Following take off from BAH passing approximately 15000ft, a dusty/damp haze was visible entering the flight deck from the air conditioning. Haze cleared after approximately 30 seconds. Haze recurred on approaching the Biggin hold, coincident with thrust levers opening. P2 (PF) donned oxygen mask as a precaution. Final approach and landing was carried out clear of any haze. There have been a number of incidents in which the F/D crew reported a smoke/haze/smell in the F/D. This incident has been investigated and includes a number of other MORs. The operator's engineering investigation was extensive and inconclusive as to the actual causes, small amounts of surface dust were found within the area of the flight crew shoulder harness heater ducting on a number of aircraft inspected during this fleet wide campaign. However, the amount of dust found was not considered to be unusual or abnormal. See also 200406921, 200407073, 200407828, 200502435 and 200504014. CAA Closure: The hazard is acceptable provided the frequency remains low.
5-Apr-2005	BAe 146	200502407	Engine vibration / fumes in flight deck which cleared after engine shut down
7-Apr-2005	EMB145	200502556	BRISTOL / CAA Pretitle : Strong smell of fuel in air conditioning system after APU start on the ground. APU fuel start nozzle was replaced. CAA Precis : Following two unsuccessful attempts to start the APU whilst airborne, it was subsequently started after landing and a strong smell of fuel was immediately evident on the flight deck and in the cabin. The APU was then shut down, the recirculation fan and ECS selected off, the flight deck ventilated and the smell dissipated. The aircraft then taxied onto stand. Inquiries reveal that post-flight inspections were accomplished with no faults. During fault investigation review on 26 April the APU fuel start nozzle was replaced. Nil reports or recurrences since that intervention. CAA Closure: The hazard is adequately controlled by the actions stated above.
12-Apr-2005	B757	200502822	G-BPEE / ASR / MOR / Lisbon / oily fumes on flight deck / CAA Pretitle : Oily fumes on flight deck / CAA Precis : On taxi in after landing during APU start sequence, a noticeable oil smell was apparent on the flight deck. The left pack was selected off as the aircraft approached the stand and the smell dissipated. See also 200408448. Investigation being progressed under 200401271.

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15-Apr-2005	A319	200502891	ASR / MOR / BA853 / PRG-LHR / Prague / CAA Pretitle : During initial climb, slight engine oil fumes were experienced on the flight deck via the air conditioning system. CAA Precis : At acceleration altitude and for about 5 minutes, slight engine oil fumes were experienced on the flight deck. The cabin services director was asked to enter the flight deck and was able to confirm the presence of fumes. The air conditioning pack flow was at the 'LO' setting and some minutes after re-selecting this to 'NORM' the smell disappeared. At no time were any fumes evident in the aircraft cabin. See also 200508136. NOTE: CAA Precis did not mention: 'A decision was made to assess the extent of the contaminat for a couple of minutes before using oxygen masks and fortunately the fumes disappeared.'
19-Apr-2005	BAe 146	200502849	AAIB initial notification / P2 became felt sick on descent & used 02 /dust & strong smell in cockpit / Swiss authorities investigating
20-Apr-2005	A319		ASR / BA905 / FRA-LHR. Slight smell of fumes (burnt oil from air conditioning) was apparent in flight. Engineering found the APU generator oil seal leaking.
23-Apr-2005	B757		G-BPED / ground crew noted more smokey than usual. P2 said it was nothing to worry about & not really a problem
25-Apr-2005	BAe 146	200503053	G-JEAX / AAIB initial notification / Fumes on flight deck / 02 / AAIB / CAA Pretitle : AAIB Initial Notification: Fumes on the flight deck. Oxygen masks donned by crew. Air and oil leaks were discovered from the APU; these were rectified. CAA Precis : Investigation, including the use of a borescope, revealed no residues indicative of oil leakage. Both air conditioning packs were inspected and nil defects found. Air and oil leaks were discovered from the APU; these were rectified. A further air leak from the APU turbine housing was also rectified. SB 21-156 was accomplished with nil defects. CAA Closure: The hazard is adequately controlled by existing requirements, procedures and documentation.
25-Apr-2005	BAe 146		G-JEAX / EDI - SOU / Divert BHX / BE 767. Smell/Fumes in Cabin led to Divertion to BHX Cabin Crew Unwell.
28-Apr-2005	D328	200503101	Edinburgh / CAA Pretitle : Slight smoke in cockpit and cabin. PAN declared. Investigation by an EASA Part 145 approved organisation found no problems. CAA Precis : Descending through FL100 at approx 30 DME south of Edinburgh, smoke developed in the cockpit and subsequently, in the cabin. The crew donned oxygen masks and established communications. However, within about 20-30 seconds, the smoke disappeared. No warnings were displayed on EICAS and, as the aircraft was being vectored for the approach, the flight continued with a PAN being declared as a precaution. The landing and subsequent passenger disembarkation proceeded uneventfully. Investigation, including a radio check by an EASA Part 145 approved organisation, found no problems. There have been no subsequent reports of any radio problems. CAA Closure: No further CAA action required at this time.
1-May-2005	B757		Accra-LGW / Smelt fumes in climb. All 3 pilots smelt & tasted oil with APU on / ASR / Blood tests (found nothing) advised should not have done. Smelt fumes again / gearbox chip detector& high left oil usage.
1-May-2005	B757	200503234	Maintenance review noted 3 reports of cabin odour events on same first flight of day ex LHR & investigating oil levels
1-May-2005	A320		IPA / Fumes MEL'd & told must go despite not happy. BAHS (British Airways Health Services) said no health problems possible / ASR / engine changed
5-May-2005	B757	200503316	Oil fumes on descent / oil levels overfull. Investigation being progressed under 200401271.
6-May-2005	A319		BA964 / G-BUSF / Oil smell on takeoff and landing / No. 1 engine overfilled

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8-May-2005	BAe 146		G-CFAA / BA8727/ ASR / During engine start APU supplying air conditioning, abnormal 'rubbery' smell in the forward pax cabin / pax disembarked normally / investigations failed to replicate the fault / low risk
11-May-2005	BAe 146	200503441	G-CFAC / LCY / Smoke in pax cabin after landing. Smoke in passenger cabin after landing. Post-flight engineering inspections were accomplished and no faults were found. After landing, smoke was reported in the cabin and as the aircraft pulled onto stand the smoke dissipated. The emergency services were not requested, although engineering assistance was sought. Post-flight engineering inspections were accomplished and no faults were found. See also 200506025 and 200507452. CAA Closure: The hazard is adequately controlled by the actions stated above
12-May-2005	B757		G-CPEL / BA1329 / NCL-LHR / ASR / Oil smell on ground when pack selected on with engines shutdown. On rotation and on descent transient reoccurences occured but not as strong as on the ground so oxygen not used.
13-May-2005	A320		SEE BA 1324 SUMMARY / G-BUSF / 24 MAY 2005 WHICH REFERS TO THIS EVENT
16-May-2005	A320		SEE BA 1324 SUMMARY / G-BUSF / 24 MAY 2005 WHICH REFERS TO THIS EVENT
21-May-2005	A320	200504059	G-TTOD / Konba. Electrical burning smell in forward toilet area. In-Flight Entertainment (IFE) suspected cause. Engineering investigation could not reproduce the fault. No further reports. From CAA MOR 200504059. During the climb, an electrical burning smell was evident in the forward toilet area. The cabin crew checked the toilet for heat/smoke and switched off both galley ovens and the IFE. The smell then dissipated. On switching the IFE on again the smell returned, therefore it was immediately switched off again and isolated using the circuit breakers. The toilet and forward galley were monitored for the remainder of the flight as a precaution. Engineering investigation found no fault with the IFE equipment and the defect could not be reproduced. The toilet and galley equipment was checked, no faults found. The a/c was returned to service. No further reports were received
21-May-2005	A319	200503749	G-EUPE / BA 913 / ASR / MOR / FRA-LHR / Acrid fumes on start up & Take-off / All crew could smell & taste CAA Pretitle : Acrid fumes inside aircraft during APU start/bleed on take-off in heavy rain. Caused when the APU ingests moisture which collects contamination on the way in, leading to a transient smell. CAA Precis : The APU was started on stand prior to passenger embarkation and when the bleed was selected on, the aircraft filled with acrid smoke. The bleed was turned off, both packs were then tried in turn and the smoke dissipated over five minutes. Later during the take-off roll, with TOGA power set, the fumes returned but again cleared after five minutes following pack flow reselection. All crew said to have remarked that they could taste the fumes in the back of their throats. This is a known phenomenon in heavy rain where the APU ingests moisture which collects contamination on the way in, leading to transient smells. Engineering operated air conditioning packs for extended period with no recurrence, and aircraft operating normally since event. CAA Closure: The hazard is adequately controlled by the actions stated above.
24-May-2005	A320		SEE BA 1324 / G-BUSF / SAME DAY BELOW (24 May 2005) MAN-LHR - Accrid oily smell on flight deck.

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24-May-2005	A320	200506257	ASR / MOR / G-BUSF / BA1324 / LHR-NCL / For sector MAN-LHR & LHR-NCL there was a strong oily accrid smell on flight deck for 3 minutes after take off, and at various points during descent and during the landing roll. The aircraft had a previous history on 13 May 2005 and 16th May 2005. Engineering suggested turning pack 1 off for return flight to LHR. CAA Pretitle : Intermittent strong, acrid 'oily' smell on flight deck. Recurring problem. The importance of attention to detail when remedial is being carried out has been stressed. CAA Precis : Investigation found two possible sources of oil which could have entered the compressor airflow upstream of the customer bleeds to cause these reports. Both of these sources have been implicated as being likely causes of oily smell reports in the past. In this instance, the prime source was most likely from the nrs 1 and 2 bearing cavity drain. This engine had only operated for 613 hrs/ 565 cycles since the last shop visit. During that visit, the nr3 bearing aft stationary air/oil seal had been replaced and the nrs 1 & 2 bearing cavity drain seal would have been renewed on re-assembly. The importance of attention to detail when work is being carried out at the critical, air/oil sealing locations and of the implications of oil entering the cabin and flight deck air systems has been reiterated to the overhaul agency. CAA Closure: The hazard is acceptable provided the frequency remains low.
25-May-2005	B757		Fumes
27-May-2005	EMB145	200504091	EDI / Smoke and fumes in cabin whilst aircraft parked on stand. Crew vacated aircraft - effect of smoke inhalation reported, slightly sore throat and mild dizziness / oil was seen dripping from the APU compartment. CAA Precis : On entering the aircraft, the crew noticed that it seemed "hazy" with a slight smell. Pack 2 was ON. The cabin quickly filled with smoke and the toilet smoke warning sounded. Pack 2 and APU were switched OFF and the aircraft de-energised. The toilet was inspected for source of fire or smoke - nothing found. Due to air contamination the crew vacated the aircraft leaving it under engineering supervision. Crew members reported effect of smoke inhalation - slightly sore throat and mild dizziness. On further investigation oil was seen dripping from the APU compartment. This was not present on either the engineering PDI, or the Captain's pre-flight checks.
27-May-2005	EMB145	200504111	Unusual smell (similar to TCP cleaning product / Detol) on flight deck and in passenger cabin. Flight deck crew donned oxygen masks and returned to the departure airfield.(Company report- G-ERJG / BA1606 / At approximately 2000 ft acrid 'TCP-like' fumes sudddenly became evident in the Flight Deck and were then reported in the forward cabin. Both Flight Crew donned oxygen masks / source was not apparent and / Enginering inspections subsequently were unable to find any fault / low risk)
28-May-2005	B757		G-BPEJ / not written in defect log as P2 said could not smell fumes

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28-May-2005	B777	200504014	CAA Pretitle : Smoke/fumes on flight deck - recurring problem during descent. Crew donned oxygen masks. No obvious fault found even after extensive investigation. CAA Precis : Smoke/fumes observed at top of descent when the throttles were closed. Oxygen masks were donned as a precaution despite the rapid dissipation of the smoke/fumes. The smoke/fumes were observed twice more during descent and on both occasions again quickly dissipated. A slight musty odour was apparent although there was no strongly discernible smell. Crew oxygen masks were worn for the remainder of the flight as a precaution. Investigations reveal that there have been a number of incidents in which the flight deck crew reported a smoke/haze/smell in the flight deck. The operator conducted an extensive investigation, which was however inconclusive but small amounts of surface dust were found within the area of the flight crew shoulder harness heater ducting on a number of aircraft inspected during this fleet wide campaign. However, the amount of dust found was not considered to be unusual or abnormal. See also 200407073, 200407828,200502435 and 200504014. CAA Closure: The hazard is acceptable provided the frequency remains low.
29-May-2005	B777		G-VIIF ? / At TOD smoke haze & slight musty smell returned & disappeared 3 times / 02 / Med advice sought
30-May-2005	B757	200504003	G-CPEL / ASR / MOR / BA915 / FRA-LHR / O2. Strong acrid smell on take off, which was confirmed by both pilots and CSD / 02 / Smell isolated to LH pack and flight continued. Subsequent multiple transient smells in both flight deck and cabin during descent with crew again using oxygen as a precaution.
3-Jun-2005	B757		G-CPER / ASR / MOR
12-Jun-2005	B737	200504955	G-IGOI. Budapest.Electrical burning / overheat smell during descent. A thorough engineering inspection was undertaken with no faults found. No further reports of this occurrence. While passing FL270 during descent, a distinct electrical burning or overheat smell / odour was noted in the flight deck. The First Officer donned his oxygen mask but a search of the cabin and cockpit found no visible smoke or irritation in either compartment. The smell disappeared after approximately three minutes. Following an uneventful landing, cabin crew reported that an "electrical" smell was momentarily detected during inspection of the rear toilet. A thorough engineering inspection was undertaken with no faults found. Subsequently, a review of tech log pages from the occurrence date to 29-Jun-2005 revealed no further reports of this occurrence. CAA Closure: The hazard is acceptable provided the frequency remains low.
12-Jun-2005	A319	200504463	G-EUPL. PAN declared due to electrical burning smell. Straight-in approach given. Invesigation found no defects. Investigation found no defects and no further similar defects have been reported on this a/c to date. CAA Closure: The hazard is acceptable provided the frequency remains low.
13-Jun-2005	EMB145		CC / Dead sock smell on descent. Dead sock smell was experienced on descent on BM405/6, Pack 1 selected off on descent. BM407/408, no smell apparent. This a/c has a history of this problem. Cause: unknown. Suggestion: Engineers stop signing the problem off, asking for more history. There is now enough history to say there is a problem with this aircraft. Note: 4 other B Defect entries

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15-Jun-2005	BAe 146		G-MABR / BA4328 / ASR / fuel smell in the rear of the pax cabin, evident to a passenger and rear cabin crew, before and after the APU had been started during descent / unable to replicate the fault and release to service was made /low risk
20-Jun-2005	A320	200504869	Smoke / MAYDAY / Diversion to MAN
22-Jun-2005	EMB145	200504797	G-ERJF / MAN. Electrical burning smell on flight deck / PAN / in-flight return / AFS / 02 Electrical burning smell on flight deck. PAN declared and in-flight return. Nr2 Radio Management Unit (RMU) was found overheating and was replaced. Immediately following take off, an electrical burning odour was noted in the flight deck. A precautionary return to the departure airport was initiated, following which the smell intensified. PAN declared and the crew donned oxygen masks. During the return it was noted the First Officer's R/T transmissions were intermittent and broken. The aircraft landed normally with emergency services in attendance. Subsequent engineering inspections found nr2 Radio Management Unit (RMU) was overheating and it was replaced. Engineering re-powered the aircraft initially on APU for approximately 20 mins then on GPU with no odour. Extensive disassembly and reassembly of a number of candidate panels and components revealed no abnormal odours. Afterwards, the a/c ground power was left on for 2 hours with systems running and windscreen heating on - no abnormal odours presented. The aircraft was monitored for one month after this event with no recurrence. CAA Closure: No further CAA action required at this time.
22-Jun-2005	A320		Strong smell of gas in cabin / PAN / Diversion to MAN
25-Jun-2005	BAe 146	200505828	AAIB Initial Notification: Flight deck smoke - emergency procedure applied - aircraft returned and landed. Subject to Italian authority investigation.
30-Jun-2005	BAe 146		BHX-EDI / ASR / MOR / Capt- FO- CC unwell making small errors (slow to put gear down)
1-Jul-2005	BAe 146		G-MABR / APU removal due fumes- failure of a compressor support bearing
1-Jul-2005	BAe 146		G-BXAS / oil smells-internal contamination (smoke from the exhaust) caused by failed turbine bearings.

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2-Jul-2005	B777	200505319	G-ZZZC / LHR. Burning smell in cabin. Investigation found the potable water compressor to be the source of the burning smell; the cause was a failed motor. Item overhauled and debris removed. The security search team reported a smell of burning in the area forward of door 4R. Trace action found the potable water compressor to be very hot and the compressor c/b to have tripped. The c/b was capped and the compressor connector disconnected, capped and stowed. An ADD was raised iaw MEL 38-10-1. A large quantity of paper, in flight literature, sweet wrappers etc were found in the area of the compressor and the APU battery. Initial investigation suspected the APU battery. It was during this investigation that the potable water compressor was identified as the source of the burning smell. Fortunately, the circuit breaker had tripped. In addition, a large amount of debris; paper, in-flight literature etc was found; this was promptly removed. Workshop strip analysis of the compressor found the cause to have been a failed motor. Two actions have been completed: the potable water system has been added to the AMM as a possible source of burning smell in the cabin and monitoring introduced for early signs of water system failures. It is believed the debris enters the sidewall liners through displaced cabin air return grilles. There has been a problem with the grilles and this has been addressed. To prevent a recurrence, an additional maintenance task has been introduced at a 2A check (150 days) to check the grilles for correct installation and security. See also 200205944 and 200407947. CAA Closure: The hazard is adequately controlled by the actions stated above.
3-Jul-2005	BAe 146		G-CFAH / complete oil loss - smelt by several crews - P1 said "normal BAe 146 smell' / P2 ill still weeks later / P1 suffered effects later- 3 engine ferry next day / ASR x2
4-Jul-2005	BAe 146		G-CFAH / After arrival of ferry flight after incident the previous day, both pilots had sore throats with P2 also having a headache / Suspected to be due to contamination of air conditioning system with oil / Both pilots have since advised they have suffered from additional related symptoms, (ulcerated throat skin rashes , headaches, stomach upsets, nausea, numbness, tingling fingers which a re believed to be consistent with exposure to organophosphates / Smells and irritants from burning organic compounds from within the engines are known to produce harmful volatile organic contaminants. Oil leaks within the engine / APU have been noted in the past to be the major cause of the reported contamination / Engineering Review, ETRs TS4138R4 / M0006R2 issued 100805 with priority 'M' compliance, adding aircraft of this fleet to the requirement (AD) for inspection of : 1) engine oil seals, APU and ECS jet pump / air conditioning pack 2) air conditioning ducts for signs of oil contamination, with both requiring initial inspection within 500 flights and repeated every 500 flights / 'C' Check respectively. Engineering also advise that a new filter, designed to exclude 'volatile organic compounds' will become available late 2005 / no immediate safety action required / medium risk -see 23/9/05
5-Jul-2005	A319		G-EUPO / LHR - FCO / FL150 to FL100 with a smell of oil / ASR

6-Jul-2005	EMB145		CC / Flight Deck - Smell during ice protection activation. Unusual smell in flight deck noticed when ice protection was in use. Smell came when system on and went as soon as system off. No smell was noticed by pax or Cabin Crew. During previous sector, we noticed the same smell but it was only when we realised that had also been when the ice protection was activated. Smell during ice protection use.
11-Jul-2005	B737		BHX-PMI / Diverted into Stn / contaminated air - suspected hydraulic leak
12-Jul-2005	A320	200505582	On taxi out intermittent smell of electrical/plastic burning in the rear cabin. The aircraft returned to stand / extensive investigation was carried out, which revealed nothing untoward.

12-Jul-2005	B737	200505593	G-ZAPM / Burning. A MAYDAY was declared and the flight crew donned oxygen masks. The smoke dissipated during short finals. Air contamination/odour in cabin and flight deck. P2, cabin crew and some passengers affected by fumes. Diversion to Stansted. PAN declared. Hydraulic reservoir pressurisation drain bleed was blocked. During climb at FL150 to FL190, a slight odour was evident in the forward cabin and the attendants reportedly felt light-headed, dizzy and nauseous. Cabin pressurisation was checked but no faults found. P2 then smelt the odour, which had now become more pungent. The aircraft levelled at FL210 and although it was re-cleared to climb to FL290, the crew requested to remain at FL210 to evaluate the problem. There was no smoke or obvious signs of distress among passengers so the flight continued. As climb commenced to FL290, a deterioration was evident in the forward cabin crew and some passengers. Oxygen was administered to the nr1 cabin attendant and when the nr4 was seen to be distressed, a decision was made to divert to Stansted for engineering support. P2 then reported feeling light-headed but recovered to carry out duties during descent. As a precaution, the flight crew donned oxygen masks and declared a PAN for an expeditious approach. In descent, the rear cabin crew and other passengers now began to feel unwell. Uneventful approach and landing carried out at Stansted. All passenger doors were opened for ventilation and passengers disembarked with no obvious signs of physical distress. The crew were taken to hospital for precautionary evaluation and subsequently released. Defect could not be reproduced in subsequent troubleshooting iaw the AMM, although RH and LH air conditioning pack water separation bags were replaced as a precaution. Total aircraft hours/landings 25465.02/14281, total aircraft hours/cycles since inspection 16.40/21. Further inspection found the hydraulic reservoir pressurisation system drain bleed caps blocked - these were cleaned and refitted iaw the AMM. A leak was found from the RH hydraulic reservoir pressurisation system - the reservoir pressure direct reading gauge in the main gear bay was replaced and leak checked iaw the AMM. The re-circulation fan filter was inspected with no faults found. Based on these findings the most probable cause of this event was the blockage of the hydraulic reservoir pressurisation drain bleed caps. An engineer remained with the aircraft for several days after the event as a safety precaution, however no further incidents were reported. A fleet check has been done with no faults found. Additionally, routine repetitive inspection of the caps will be introduced at the next maintenance programme amendment. CAA Closure: The hazard is adequately controlled by the actions stated above.
15-Jul-2005	B757		G-CPEO / BA695 / HAM-LHR / ASR. Shortly after leaving hold crew experienced transient fumes for a short duration.

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15-Jul-2005	BAe146		G-BXAS / BA 1654 / Previous report oil smell in cabin led to APU inop under ADD / OAT of +30degC led to Flight Deck and pax cabin temperatures becoming very high and causing obvious cabin crew and pax discomfort and distress. Following Engineering inspections, APU P/N 4501690B was replaced, and ADD cleared/ Risk minimal / ASR
19-Jul-2005	B757	200505942	G-CPEV. LGW. Fumes in aircraft. Members of cabin crew affected by fumes. Investigation found this occurrence was caused by over filling of engine oil systems. Immediately after take-off the P1 was aware of a faint smell of vaporised/burnt oil and also experienced a slight stinging in the eyes. These effects quickly disappeared. At the top of climb the flight supervisor reported that 2 of the 3 cabin crew situated at the front of aircraft and 1 of the 2 at the rear of the aircraft had reported a strange smell and were feeling slightly unwell (dizzy and nauseous). The smells and symptoms quickly disappeared and the flight was continued. On the return sector the same smell was detected briefly after take-off by both pilots. Investigation found this occurrence was caused by over filling of engine oil systems. Ground runs of the aircraft engines were unable to reproduce the fumes. There have been no previous reports of over filled oil systems on any of this operators aircraft and no subsequent reports regarding this aircraft. The operator confirms that ground staff are well aware of the procedure for replenishing oils and continuation training regarding ground servicing tasks is carried out at regular intervals. CAA Closure: The hazard is adequately controlled by the actions stated above.
22-Jul-2005	BAe 146		G-CFAE / BA 1760 / Prior to pushback an abnormal 'hot acrid' burning smell evident to both Flight Crew. No fault found / Medium risk / ASR
25-Jul-2005	BAe 146	200506097	G-JEBE / BHD. First Officer became unwell/incapacitated during fourth sector of day, requiring oxygen for last 15 minutes of flight. Investigations found no defects that could have contributed to the cause. Although no fumes were apparent, the reporter notes that the symptoms were consistent with previous occasions where contaminated air was suspected. Inquiries confirm the tech log entry, recording the single use of crew oxygen for 15 minutes. The aircraft monthly cabin air quality inspections showed nil defects. The first officer's medical report showed nil findings and no other related engineering incidents have been reported for the subject aircraft. CAA Closure: No further CAA action practicable.

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25-Jul-2005	BAe 146	200506025	G-CFAD / BA1643 / in crz 2 cabin crew became dizzy, light headed, headache, nauseous with one using 02 / air conditioning contamination suspected / pilots not concerned enough to use 02, however Capt felt unwell on return sector / engineering released a/c for use in fresh mode only / 1 cabin crew member off work a week after this unwell / ASR / medium One flight crew member and two cabin attendants felt dizzy and unwell during climb and cruise. Oxygen administered to one cabin attendant. Cabin filters contaminated. Flight Crew reporter suspected the origin of the symptoms to have been air conditioning contamination but were not sufficiently concerned to lead to either pilot donning their oxygen mask. Flight continued with air conditioning system operated in 'Fresh' mode which draws all the air from the engine with no re-circulation of air from the cabin back to the air conditioning packs. Post flight investigation reviewed cabin filter change records and it is noted that the last filter change was completed on 11/11/04 and had run approximately 1520 flight hours up to the reported event. Scheduled change is due every 2,400 flights. Following a review of available aircraft maintenance requirements, Mandatory SBs 21-150 & 21-156 not applicable for the BAe 146 RJ series aircraft has been introduced by the company, with the support of BAe, as a requirement for the RJ fleet. This is to prevent long term build up of air conditioning system contaminates. The above requirements have been introduced under existing (146) ETRs TS4138 and M0006 on 8/8/05 which will be complied with at the next appropriate base inputs with repeat requirement. Technical Instruction 146-21-02 has been amended to include the above references when carrying out investigations into adverse cabin air quality reports. See also 200503441 & 200507452. CAA Closure: The hazard is adequately controlled by the action stated above.
28-Jul-2005	B737	200506131	CAA Closure: The hazard is adequately controlled by existing requirements, procedures and documentation
29-Jul-2005	BAe 146		G-JEBE / No Techlog Entry / First Officer not feeling well on sector 4 of 4 sector day / Used Oxygen for last 15 minutes of flight / No Odours or Fumes present / However Symptoms were consistent with Fume Events & Contaminated Air on previous Occasions / ASR Filed, Air Quality Not Filed, as there Were NO FUMES detectable / MOR
30-Jul-2005	A319		G-EUPG / ASR / BA696 / LHR-VIE. Perceptible oil smell on climb from 1500 ft to 6000 ft. When aircraft levelled and power reduced smell dissipated. No fault found
1-Aug-2005	B777		G-YMMB / BA96 / acrid fumes / flight cancelled
1-Aug-2005	BAe 146		GCFAF / BA 7844 / ASR / After start with APU air and both air conditioning packs were on, an abnormal smell resembling 'caramel' was briefly evident to bothPilots in the Flight Deck initially on the LHS and then ceased / it was decided to complete the flight as intended. Engineering were subsequently unable to replicate the fault prior to release to service. Note a similar event on the same aircraft two days later, recorded under 710/05/146
3-Aug-2005	BAe 146		GCFAF / BA1661/ ASR / abnormal 'oily' smell was evident to both Pilots in the Flight Deck on taxy for t/off / APU air and both packs were selected off and the smell ceased. The flight was completed without the use of APU air / similar problem same aircraft 2 days prior / APU replaced & de-oil solenoid / low risk.
3-Aug-2005	B777		G-YMMB / BA96 / fumes & smoke warning / PAN - diversion / fumes filled cabin on ground /
4-Aug-2005	BAe 146		Fumes

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4-Aug-2005	Dash 8		G-JECE / -400 / oil vapour / chip fat fryer smell / 02 / crz-priority ldg / "fumey on previous sector" / Paramedics (BP & pulse)
4-Aug-2005	B757		G-CPEL / transient fumes on t/off (QRH not done as transient). Fumes returned later with pilots getting eye- nose & throat irritation. Engineers reluctantly investigated & found hydraulic leak. MEL'd with one pack off. Fumes returned on rt flight / 02 / ASR & MOR
5-Aug-2005	B777		G-YMMB / BA96 / Fumes still present / possibly oil from APU / smoke fumes warning after dept / PAN /
5-Aug-2005	EMB145	200506290	AAIB Initial Notification: Smoke in aircraft / Crew on oxygen / Passengers disembarked on runway and taken by bus. Subject to AAIB AARF investigation. G-EMBP / ASR / BA1767 / abnormal burning smell and hazy smoke in pax cabin / 02 / EAP Card 11 for air conditioning smoke actioned/ fumes cleared then reoccurred/ PAN / AFS /Pax disembarked normally on runway / re-circulation fan part replaced / Strip report of failed component shows major internal damage to stator and rotor components and was confirmed as source of burning smell, but does not isolate cause. Engineering / low risk / isolated event)
5-Aug-2005	EMB145	200506290	G-EMBP / En Route. Smoke in aircraft. Crew on oxygen. PAN declared. Uneventful landing. Recirculation fan bearing failed. AAIB AARF investigation. AAIB Bulletin 12/2005, ref: EW/G2005/08/08 - Summary: The aircraft was on a scheduled flight from Frankfurt to Birmingham. Whilst in the cruise at FL360, the cabin crew observed some hazy smoke in the central cabin area. The senior crew member informed the flight deck crew who donned their oxygen masks and declared an emergency to ATC. Because of information passed to them from an onboard positioning crew, that they had experienced an air conditioning pack problem earlier in the day, an initial descent to FL240 was carried out in anticipation of possible single pack operation. The emergency/abnormal procedure for 'Air Conditioning Smoke' was carried out following which the cabin crew reported that the smoke had cleared. The commander decided to continue the flight to Birmingham and there was no re-occurrence of the smoke en-route. Descending through FL50, towards the final approach to land, the cabin crew informed the commander that the smoke had returned and was now more to the front of the cabin area. A 'PAN' call made and the flight crew put on their oxygen masks again. ATC were informed that it might be necessary to carry out a passenger evacuation on the runway after landing. Shortly before landing the cabin crew advised the commander that the smoke had cleared. After landing the commander stopped the aircraft on the runway and liaised with the Airport Fire Service (AFS) who were in attendance. AFS personnel came on board the aircraft and were unable to find any evidence of smoke or fire. The passengers were evacuated, as a precaution, following which the aircraft was towed off the runway to a stand. The source of the smoke was subsequently traced to a faulty bearing on the cabin air recirculation fan. The recirculation fan would have been turned 'Off' as part of the procedure carried out by the crew. CAA Closure: The hazard is adequately controlled by existing procedures, requirements and documentation.

8-Aug-2005	B757	200506760	TF-FIE / Stansted.Aircraft returned due to smoke in cockpit. LH engine nr1 bearing failed, allowing oil to contaminate air conditioning system. AAIB AARF investigation. AAIB Bulletin 2/2006, ref: EW/G2005/08/16 - Summary: The aircraft was taking off from Runway 23 for a short night flight to Liege, Belgium; the First Officer was the handling pilot. The take off was uneventful until, at about 5-10kt below V1, the captain thought he might have seen some smoke in the cockpit. At this time the first officer was unable to confirm the presence of smoke. At approximately 500ft, the captain turned up his reading light and called that he could see smoke and the first officer confirmed that he could smell it. They called the control tower, explaining the circumstances and requesting a turn-back and landing. The controller asked if they were declaring an emergency but the captain declined, saying that the smoke had cleared, however he still preferred to return. They were given radar vectors to 5 to 6 miles finals and the aircraft landed on Runway 23 without any difficulties after a total airborne time of 11 minutes. The Airport Fire Service attended and, after a brief inspection, the aircraft was taxied back to the gate with everything appearing normal. A technician from the maintenance provider attended and agreed that he could also smell an odour of hot oil, apparently emanating from the air conditioning system. Subsequent inspection suggested that an oil leak, apparently from the No.1 bearing in the left engine, had been ingested into the intermediate pressure compressor and thence into the air conditioning bleed air. Initial actions were to change and inspect the pressure and scavenge oil filters but the operator subsequently opted to change the left engine. After this the aircraft was released to service with no further reports of air contamination. A subsequent strip examination of the engine showed that a cracked No.1 bearing front ring seal had been responsible for the oil leak. CAA Closure: The hazard is adequately controlled by the actions stated above.
11-Aug-2005	SF2000	200506496	CAA Pretitle : AAIB Initial Notification: PAN declared due to smell of smoke. One engine shut down and aircraft returned safely to Aberdeen. No reported damage or injuries to 29 POB. CAA Precis : Smoke / haze noted in the cabin during climb out although there was no fire warning. MAYDAY declared and a return to departure airport initiated. During the turn, nr2 engine failed, requiring the crew to shut down the engine with the APU starting automatically. Prior to landing the smoke / haze disappeared. Single engine landing completed with emergency services in attendance. See also 200507827.

13-Aug-2005	B757	200506564	G-BPEC / LHR-MAD / BA 456 / Strong oily fumes on t/off - strong, noxious fumes were evident on the flight deck / Oil levels overfilled / P2's 3rd event / ASR / MOR / O2 used CAA Pretitle : Strong fumes on flight deck. Oxygen used until fumes cleared. It has not been possible to identify cause of transient oil smell but it is felt that over-servicing was not a contributory factor. CAA Precis : During initial climb strong, noxious fumes were evident on the flight deck. Both pilots went into oxygen for 4 minutes until the fumes cleared. It was established that only the flight deck was affected with nothing being smelt in the cabin, indicating LH air conditioning system contamination. On arrival the engineer found both engine oil levels overfilled. The subject flight was the first of the day, prior to which the aircraft had been in the maintenance hangar overnight. Oil drained to max level as per MM 12-13-01. Investigation found both engine oil levels above the operator's imposed limit but well below the OEM's recommendation. 1/2 quart of oil was removed from both engines. The aircraft had had a daily check performed at LHR the previous night and no oil was added to either engine. At the time of this daily, the aircraft had not been flown since the previous daily but the engines were not run to carry out the oil level check as required. While it seems logical not to run the engines to re-establish oil levels if the aircraft has not flown since the last daily, there is no authority within the daily check to do this - this aspect is under review by operator. It has not been possible to identify the cause of the transient oil smell but it is felt that over-servicing was not a contributory factor. CAA Closure: The hazard is adequately controlled by the actions stated above.
17-Aug-2005	BAe 146		G-JEBD / flight crew effects reported yet no apparent fumes
18-Aug-2005	BAe 146		G-JBED / 2 cabin crew reported light headedness & slight headaches
19-Aug-2005	BAe 146		G-JEBD / flight crew effects reported yet no apparent fumes / Captain fell asleep
20-Aug-2005	BAe 146		G-JEBD / No Techlog Entry / 6 sector day, situation similar to incident G-JEBE on 27/08/2004 Symptoms consistent with Fumes and Contaminated Air but No Fumes or Odours present / Errors made: Oversped N1 on 2nd Sector. Off course on 5th sector. Breath test after flight showed Phenol, C3 & C4 Benzine, Freon 141 / ASR /
20-Aug-2005	BAe 146		G-FLTA / MXP-Mikinos (diverted to ATH due fumes) / Cc collapsed & all CC had effects.: BAe to investigate
23-Aug-2005	BAe 146	200509889 200510448 200510449	CAA Pretitle : P2 illness / incapacitation possibly due to contamination of air conditioning system. CAA Precis : On four consecutive training flights on three different fleet aircraft over a 9-day period, the P2 considered that the aircraft air conditioning systems might have been contaminated. Abnormal smells were reported and the P2 allegedly suffered with headaches, had difficulty concentrating and focusing with spots before the eyes, and on one occasion experienced severe vomiting. Medical assistance was sought. No other members of the crew were reportedly similarly affected. Following similar reports of flight deck/cabin smells maintenance requirements have now been upgraded and ETR TS3138 and M0006 have been amended to include inspection requirements of SB 21-150 and SB 21-156 (inspection of ducts/air conditioning units and removal of contaminated parts). Fleet Technical Review initiated with the introduction of trial filters in the RJ Series cabins and flight decks. See also 200510448 and 200510449.

25-Aug-2005	BAe 146		G-JEBD / Flight crew experienced similar symptoms yet no fumes present / Errors made: Took off from BHD in Wrong Flap Setting even though P2 had mentioned they had symptoms of contaminated air and that both should be more alert. / NO ASR or air quality report filed as no fumes or odours pressent / Same P2 on 17, 19, 20 & 25 Aug, 2004 on G-JEBD with symptoms present on all days
26-Aug-2005	A319		G-EUPC / BA464 / LHR-MAD / ASR Oil smell from 1500ft on climb to 22000 ft and from 12000 ft in descent until Pack 1 switched off and smell receded.
26-Aug-2005	A319		G-EUPC / BA465 / MAD-LHR / ASR Oil smell on take off. After take off Pack 1 selected off. No fault found
26-Aug-2005	A319		G-EUPM / BA364 / LHR-LYS / ASR / MOR Perceptible oil smell in descent from 10000 feet to touchdown only flight deck. Oxygen not used.
27-Aug-2005	B757	200507223	Smoke on flight deck after shut down and passenger disembarkation. Fire services in attendance.
29-Aug-2005	B757	200507349	G-CPEO / BA1459 / ASR / MOR / EDI-LHR When the engine anti-ice was selected on during descent a sweet oily smell was noticed by both pilots. The smell cleared (or appeared to clear) when the anti-ice was selected OFF. This defect was entered into the Tech Log but was later discovered to have been signed off by an engineer with the statement 'Info noted request further report'. The reporter considers that this is inappropriate in view of the significant flight safety and medical aspects of exposing crews again to potentially contaminated air without any rectification action having been carried out. The reporter confirms that the aircraft should be despatched to comply with its design certification (i.e. EASA / JAR 25.831) by engineering action or actioning the MEL. During the night after the event the P1 suffered with gastro intestinal problems, which the reporter confirms have only ever affected the P1 following contaminated air events. The reporter suggests that due to the repeated cases where crews have been unable to detect contaminated air (as many ingredients have no smell) it might be prudent to take early action of fitting contaminated air detection systems as recommended by the international industry body ASHRAE SPC 161 or to fit available filtration systems.
29-Aug-2005	Dash8		GBRYX / BA1862 / warm electrical smell in cabin / crew could not find source or isolate / No fault found / ASR / 'Risk-low'
30-Aug-2005	BAe 146	200510448	G-CFAA / P2 illness / incapacitation possibly due to contamination of air conditioning system. On four consecutive training flights on three different fleet aircraft over a 9-day period, the P2 considered that the aircraft air conditioning systems might have been contaminated. Abnormal smells were reported and the P2 allegedly suffered with headaches, had difficulty concentrating and focusing with spots before the eyes, and on one occasion experienced severe vomiting. Medical assistance was sought. No other members of the crew were reportedly similarly affected. Following similar reports of flight deck/cabin smells maintenance requirements have now been upgraded and ETR TS3138 and M0006 have been amended to include inspection requirements of SB 21-150 and SB 21-156 (inspection of ducts/air conditioning units and removal of contaminated parts). Fleet Technical Review initiated with the introduction of trial filters in the RJ Series cabins and flight decks. See also 200509889 and 200510449.

31-Aug-2005	BAe 146	200510449	G-CFAB / P2 illness / incapacitation possibly due to contamination of air conditioning system. On four consecutive training flights on three different fleet aircraft over a 9-day period, the P2 considered that the aircraft air conditioning systems might have been contaminated. Abnormal smells were reported and the P2 allegedly suffered with headaches, had difficulty concentrating and focusing with spots before the eyes, and on one occasion experienced severe vomiting. Medical assistance was sought. No other members of the crew were reportedly similarly affected. Following similar reports of flight deck/cabin smells maintenance requirements have now been upgraded and ETR TS3138 and M0006 have been amended to include inspection requirements of SB 21-150 and SB 21-156 (inspection of ducts/air conditioning units and removal of contaminated parts). Fleet Technical Review initiated with the introduction of trial filters in the RJ Series cabins and flight decks. See also 200509889 and 200510448.
1-Sep-2005	BAe 146		ASR / Abnormal Air Conditioning smells / engineer advised fumes smelt but could not find where from / Aircraft grounded / ASR report received back advised ‘Engineering inspections found no fault’ / During operations with the APU unserviceable, a smell, described as similar to 'damp socks' was intermittently evident in flight deck / Flight Crew discussed going onto emergency oxygen but decided that this was unwarranted / No defect was recorded after flight / similar circumstances during the subsequent flight wih the same crew recorded under 877/05/146 / low risk
1-Sep-2005	BAe 146		G-CFAB / BA 1779 / ASR / a smell described as similar to 'damp socks' was intermittently evident at various times during the flight with APU unserviceable / no faults prior to release to service / similar event during the previous sector with the same Crew recorded under 775/05/146 / low risk
4-Sep-2005	B757	200507359	ASR / MOR / LHR-EDI / G-CPEL / BA1440 After takeoff briefly oily odour / taste on flight deck / Fumes on the flight deck during descent described as 'strong odour'. On ground smell / fumes were very obvious. Comment of 'Fumes possibly been present throughout flight but flight crew may have accustomed to the smell' in ASR but not recorded in CAA database. PAN declared. Skydrol contamination in air conditioning system suspected cause. Recurring problem. A few days prior to the incident a hydraulic fluid leak had occurred in the stabiliser, which was rectified but entered as an ADD for the Skydrol to be cleaned up. Then during an earlier flight on 04 Sep 2005 fumes were experienced on the flight deck and were traced to Skydrol smoking on the APU ducting - 200507414 refers. The aircraft was despatched on the subject flight with the APU bleed locked out, but fumes were re-experienced during descent. QRH drills for smoke or fumes removal were carried out, a PAN was declared and the approach flown using oxygen - see MOR 200507414

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4-Sep-2005	B757	200507414	ASR / MOR / EDI - LHR / G-CPEL / BA1447 / Smell / fumes on the flight deck. Flight crew affected by noxious fumes. Skydrol contamination in air conditioning system suspected cause. Recurring problem / On the ground the smell/fumes were very obvious although the reporter suspects that they may have been present throughout the flight with the flight crew accustomed to the smell. Both the P1 and the P2 had a strong taste of oil fumes in their mouths, which also developed into a burning in the mouth and nose with a slight stinging in the eyes whilst on the ground. Medical advice sought. The reporter comments that oxygen had not been used during the flight because the flight crew had considered that both instances of smell / fumes were transitory, although it is possible that they had become accustomed to the smell. Subsequent investigation revealed that the APU bleed air ducting was heavily contaminated with skydrol. The reporter considered that the APU bleed air should not be used although a similar fault occurred later the same day - 200507359 refers. CAA data forgets to mention comment from ASR of: 'In latter stages of approach fumes experienced to door 3 in cabin.'
4-Sep-2005	B757	200507259	CAA Pretitle : PAN declared due to fumes on the flight deck. Squawk 7700 selected and expeditious approach given. Investigation found hydraulic fluid in the APU bleed duct. CAA Precis : Investigation found hydraulic fluid in the APU bleed duct - thought to have originated from stabilizer trim control module. Stabilizer bay area washed out and required lubrication carried out. See also 200507359. CAA Closure: The hazard is adequately controlled by the actions stated above.
5-Sep-2005	B757		G-BPEC / ASR / MOR / LHR-LIS / BA500 / During taxi, descent through 1500 feet and taxi in three transient events of contaminated air supply to the flight deck were experienced. As events were transient QRH not actioned. On turnaround oil levels found to be overfilled by engineer.
5-Sep-2005	A320	200507323	PAN declared due to smoke on the flight deck. Aircraft returned
7-Sep-2005	BAe 146		REF MOR 200507452 - same aircraft as following day / cabin crew experienced similar symptoms (light-headedness and slight confusion) and had found normal tasks difficult to achieve.
8-Sep-2005	BAe 146	200507452	G-CFAC / BA8735 / FRA-LCY / ASR / All cabin crew unwell (sickly & light headed-unable to do simple cabin crew duties- confused-spaced out) / 2 cc had similar symptoms on same aircraft day before / smell described differently by various crew / Pax became very quiet / Crew went to A&E (BP-02 levels) BAHS (British Airways Health Services) did Blood Pressure-temp- ears & throat examination) See also 200503441 (same aircraft) and 200506025.
10-Sep-2005	B757		G-BPEC / Oil Smells
15-Sep-2005	B757		G-BYAT / strong oil fumes / 02 not used as aircraft had a long history over several months and assumed must be safe or aircraft would not be flying'. Pilot advised' most pilots were not writing it up and just telling the engineers about the smells and told all OK'. Capt had headache- muscular & significant gastrointestinal problems since event / Unaware of need to use 02 in all cases of contamination or suspected contamination / ASR raised to cover medical effects
18-Sep-2005	A319	?	Contaminated Air. See 20 Sep 2006. CAA Ref: 200507741
19-Sep-2005	EMB145		GEMBE / BA4022 / abnormal 'electrical' smell near galley / door / related event 3 days later

20-Sep-2005	A319	200507741	BFS-LGW / G-HMCC / In climb, P2 (handling) puts hand on chest and complains of breathing difficulties and heart rate high. P1 initially thinks its a joke and then very quickly sees he is in trouble and takes control whilst immediately also getting strong symptoms and both crew go onto to 100% oxygen / Emergency / 7700 / ATC informed 'possible fumes' / 1 cabin crew member at same time was laughing hysterically for no reason / Hospitalized but advised too late to do tests as oxygen used / no smells / no visible fumes / ASR / No symptoms after event. CAA Pretitle : Both members of the flight crew felt dizzy and light headed during climb. Flight crew oxygen masks donned. PAN declared and aircraft returned. CAA Precis : Climbing out from BFS at approximately FL90 the P2 felt a slight dizziness followed by a rapidly increasing heart rate, describing the sensation as breathing thin air. The P1 took control and the aircraft was levelled off at FL90. All indications were normal, with the cabin ALT at 850ft increasing slowly. Approximately 10 seconds after the P2 first reported dizziness the P1 felt a similar sensation of rapid increasing heart rate and an overall uncomfortable feeling. Oxygen masks were donned and within 20-30 seconds the flight crew fully recovered. The cabin crew reported that the cabin was not affected. A PAN was declared and the aircraft returned. An uneventful landing was carried out with AFS in attendance at the gate. See also previous occurrence (200507665) dated 18 September 2005.
20-Sep-2005	B757	200507833	Barcelona / CAA Pretitle : During descent both pilots detected a strong smell of oil - both left and right engines found significantly overfilled with oil. CAA Precis : See also 200501107.
20-Sep-2005	B757		G-CPEM / LHR-EDI / BA1454 / FCR / Contaminated Air smell on pushback during engine start / After landing cabin crew reported feeling sick / dizzy. Pilots felt OK. No ASR
20-Sep-2005	EMB145	200507862	During initial climb, an electrical smell (but with no visible smoke or fumes) was reported in the galley in the area adjacent to the service door upper hinge / smell persisted for the duration of the flight / When the flight deck door was opened after landing, a smell similar to hot electrical wiring was evident / See also 200508060
22-Sep-2005	BAe 146		Refer MOR 200507889 / The aircraft was returned to service following rectification of a "significant hydraulic leak". On completion of the first flight thereafter, the crew reported a smell of oil in the cabin on landing.

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22-Sep-2005	B757	200510813	ASR / G-CPEN / BA 1463 / EDI-LHR Smelt 'fumes' on start up. Before take off P2 felt 'strange / vague' but then recovered and take off normal. In cruise no smells noticed but both crews felt nausea. No O2 used. Next day P1 Ok but P2 who had another exposure event on 20 September felt very fatigues, dizzy, nausea, vague, loss of balance. P2 rang BAHS who ststed they had lots of calls on contaminated air and that alot of this was 'somosomatic'. Would not allow P2 to speak to a doctor. P2 was formorly a registered staff nurse. Oil fumes inside aircraft after engine start. Following engine start, oil fumes were apparent on the flight deck. The fumes soon dissipated but, some minutes into flight, both flight crew suffered slight headache and mild nausea. All symptoms cleared by about 20 minutes after take off. At no time was oxygen felt to be needed or used, however, after landing both flight crew reported headache/nausea persisting. On investigation the LH engine forward bearing feed and scavenge tubes were found leaking and the seals were replaced. The leaking oil had contaminated the APU, which was subsequently replaced. See also 200508808 and 200600801.
22-Sep-2005	B757	200507897	G-BPEE / LHR-LIN-LHR / Transient fumes / Cabin crew member complained that flight deck air on approach and landing caused throat and eye irritation / CSD and Captain also noticed a bitter taste at the back of the throat. CAA: Investigation progressed under 200401271.
22-Sep-2005	B777		G-VIIW / GE90 engines: burning smell on descent into Dubai
22-Sep-2005	EMB145	200508060	G-EMBE / BA4086 / Take off rejected due to burning smell in flight deck. Fumes in front of cabin. Smell dissipated at flight idle / AFS attended and escorted aircraft to the stand / pax disembarked / no fault found / similar occurrence 3 days earlier
22-Sep-2005	A320		LHR-MXP / G-BUSC / damp ash smell briefly om t/off and TOD / nil ASR / tech log entry / no previous history / CFM engines
22-Sep-2005	BAe 146		Reporter states that over a 9 day period whilst operating on several different fleet aircraft, they considered that the aircraft air conditioning systems may have been contaminated / abnormal smells of 'sweaty socks' and 'old school dinners' occurred, associated with headaches, difficulty focusing, difficulty concentrating, spots before the eyes and on one occasion severe vomiting, for the reporter / medical assistance sought / ASR / low risk

23-Sep-2005	BAe 146	200507889	G-BZAV / BA 1740 / 3rd sector after 'massive hydraulic leak' / (same crew as previous night) / 3 Cabin crew complained of oily smells & were very tired & sleepy / F/O light headed and smell noticed on T/O & Captain noticed smell on approach and felt very tired & sleepy-mild headache and nausea. 50-60% of passengers asleep. Cabin crew advised by BAHS (British Airways Health Services) to get fresh air & see GP if still unwell. Engineering commented that ducting was contaminated & would take time to clear / ASR - An abnormal 'oil' smell occurred / Engineering suspected the smell to be the result of APU air supply and ADD P228 was raised for further operation without APU air. During subsequent inspection, an APU gearbox vent pipe connections was found loose and it was re-connected and ADD P228 cleared. Flight Operations and Engineering Reviews intend no general safety response action, but for review / general actions arising from air contamination on this fleet, see 625/05/146 - 4/7/05/ medium risk Oil fumes in cockpit and cabin. Auxiliary power unit (APU) vent pipe connection was found loose. The aircraft was returned to service following rectification of a "significant hydraulic leak". On completion of the first flight thereafter, the crew reported a smell of oil in the cabin on landing. On the first flight of the next day the smell of oil was again apparent on take off and landing. Four crew members, including the Captain, reported feeling very tired and sleepy, while another described feeling light-headed. 50-60% of passengers slept for the majority of the flight. Engineering suspected the smell to be the result of APU air supply and ADD P228 was raised for further operation without APU air. However, during subsequent inspection, an APU gearbox vent pipe connection was found loose and it was re-connected and ADD P228 cleared. See also 200507452. No further reports. CAA Closure: The hazard is adequately controlled by the actions stated above.
23-Sep-2005	B777		G-VIIW / GE90 engines: same aircraft reports fumes on approach / ASR / engineer lists as 'please report further' / Aircraft returned to service
24-Sep-2005	B777		G-VIIW / GE90 engines: Aircraft had reported fumes on previous flight (ASR filed) with engineer signing off as 'please report further' / On approach back to London after flight from Philadelphia fumes were smelt in cabin at door 4L & flight deck. P2 reported stinging eyes / no oxygen used / Capt reported fumes in tech log -'for info' / Cabin crew not advised to contact BAHS. Recently come out of major service in Cardiff
29-Sep-2005	B757		MIR-BRS / Following a continous descent (0235z) on spool up at around 1000' I detected the dreaded "oil" smell, very very light. I did not put mask on and carry out the drills as we were to close to the ground on a very demanding approach (BRS crap airport in strong wind etc) but once on the ground I turned the packs off and opened both DV windows and the smell went immediately. I filed a company FSR, filled in the technical log and the aircraft was grounded, while the engineers checked it. As I said the smell was only just detectable, I now seem to be able to detect it before the F/O, in this case tho I was flying with a training Capt (short of crews) and he detected it just prior to touchdown as well, although he was not aware what it was.

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30-Sep-2005	A319		G-EUPC / LHR-ZRH / BA714 Oily fumes after take off. Smell was reported by cabin crew in aft galley. Oxygen used.
30-Sep-2005	BAe 146	200508097	G-CFAB / BA1823 / on air supply changeover from APU to engines an oily smell became apparent in the Flight Deck and pax cabin. The smell ceased in the Flight Deck after approximately 1 minute, but remained in the rear pax cabin for an unreported period / Engineering suspected oil contamination of the engine to APU air changeover and ADD raised for continued operation with APU air inoperative / low risk / ASR / EDI CAA Pretitle : Oil smell in cockpit. CAA Precis : After take off, following air change over from APU to engines, an oily smell was apparent in the cockpit for approx one minute. A similar smell was also reported from the rear of the cabin, which seemed to last longer. Engineers suspected the APU vent valve of leaking contaminated air and dispatched the aircraft with APU air inoperative. The take off was conducted with packs off and nr4 engine bleed on. After power reduction, the packs and the remaining engine air was selected on. Immediately thereafter oil was smelt in the cockpit for about 30 seconds with nothing being smelt in the cabin. On the return sector the aircraft took off with nr4 engine air on. Nr3 engine air and pack 2 were then selected on and oil was again smelt in the cockpit. When engine 1 and 2 and pack 1 were selected on the smell cleared. Engineering found an oil leak from the bleed band area and subsequently replaced the nr1 engine.
30-Sep-2005	BAe 146		G-CFAB / BA 1824 / Following a similar event during the previous sector operated by a different crew after which the aircraft was released to service with the APU air supply isolated, an abnormal oil smell became evident in the Flight Deck but ceased after approximately 30 seconds / Reporter notes a similar occurrence on the subsequent flight Engineering subsequently replaced Engine 1 under Work Pack BHX/H/75/10/05 - low risk / ASR
3-Oct-2005	A319		G-EUPS / ASR / AMS-LHR / BA423 / Strong oily smell on flight deck from approximately 3000 ft on approach. Packs 1 and 2 switched off independently to no effect. Oxygen not used as close to landing.
5-Oct-2005	EMB145		See incident below of 5/10/05 - ASR - BA 4100 / GEMBO / 1079/05/EM4 / very strong hot electrical burning smell on pushback/ repid disembarkation / APU failure with smoke & flames / Aircraft released for positioning flight-see below / risk / M
5-Oct-2005	EMB145	200508240	Acrid smell - 'hot electrics' / APU failure during pushback. Return to stand & cautionary disembarkation / - During positioning flight with only flight and cabin crew on board following an earlier APU failure accompanied by an 'electrical burning' smell - 1079/05/EM4, an oily smell was apparent at intervals throughout the aircraft / Engineering issued Technical Instruction EMB-49-06 131005, which gives guidance to engineers with regards to purging of the bleed air system following an APU change or contamination caused by a faulty APU.
5-Oct-2005	BAe 146		G-GBED? / crew effects / no apparent fumes
6-Oct-2005	BAe 146		G-GBED?/ crew effects / no apparent fumes
6-Oct-2005	B767		G-BNWY / Ground at FRA / A CC member collapsed & vomiting / APU overfilled causing fumes in cabin which triggered fire warning

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8-Oct-2005	A319		G-EUPP / ASR / BCN-LGW / BA2487. After the descent from 38000 feet to 13000 feet there was a strong smell of oil in the flight deck and forward cabin when engines powered up. Cabin crew experienced sore throats
10-Oct-2005	B757	200508371	G-BPEK / fumes / ASR / LIN- LHR / BA561 / strong fumes in initial climb / crew effects (P1) Work Patterns 1 and 2 carried out - No Fault Found. CAA Pretitle : Fumes in flight deck during take off and initial climb. CAA Precis : During the later stages of the take off roll, both flight crew noted a strong smell of fumes. It was decided to don oxygen masks when the aircraft was cleaned up but at approximately 1000ft the fumes dissipated. No smells were noted in the cabin at that stage although later in the flight, transient fumes were detected in the mid galley area.
10-Oct-2005	L-188	200508456	G-LOFC / On ground in ABZ / Flight Neptune 873 / ASR / MOR / Engine Driven Compressors (EDCs) engine oil suspected of contaminating pressurisation bleed air. Oil in EDCs is 2380. P1 could not see P2 such was the amount of contamination in flight deck. P1 walked onto tarmac, collapsed and vomiting. Both crew significant effects for several days such as vomiting, headaches, woolly head feeling, massive fatigue, laboured breathing, numb feeling, hangover type of feeling, P1 could not 'string a sentence together'. after the event. Oil film over P2 glasses, crew and on cockpit floor / Next 4 pilots to fly the same aircraft all reported nausea symptoms. No maintenance action taken before aircraft returned to service. Several ground personnel confirmed contaminated air smell. P1 difficulty completing ASR / MOR report. On 18 October 2005 crew still not fully recovered and off work sick. CAA Write up leaves out crew effects etc..
11-0ct-2005	EMB145	200508412	Glasgow / CAA Pretitle : MAYDAY declared due to haze and burning smell in cockpit. Captain began to feel slightly dizzy, flight crew donned oxygen masks. Aircraft landed safely with AFS in attendance. CAA Precis : The only electrical selection made by the crew 30 seconds prior to this event was turning the weather radar and Lightning Strike System (LSS) to 'on'. CC / Haze and burning smell in cockpit. During descent the F/O and I smelt a strange ozone and burning smell and noticed a vague haze in the cockpit. I began to feel slightly dizzy so called for vital actions for smoke. These were actioned, we established communication and turned the recirculation fan off. The F/O continued handling and took the radio while I talked to the SCCM regarding the status of cabin. Once it was clear that the cabin was free of smoke, I took back comms and made a Mayday call to Scottish Control requesting immediate priority routing to Glasgow. We then reviewed the QRH to confirm vital actions were complete. The haze cleared on completion of vital actions so I decided not to spend time trouble-shooting a possible cause. I invited the SCCM into the flight deck and gave her a NITS brief. The landing was uneventful. When we had cleared the runway I stopped the aircraft and talked to the fire crew to appraise them of the situation. We then proceeded to stand. masks were removed when we cleared the runway and PA to pax was given during taxi to stand. The only electrical selection we had made in the 30 seconds before the occurence was turning the weather radar and LSS from Standby to ON on the Captain's side.

13-Oct-2005	B747	200508568	G-GSSB / Global Supply Systems operating for British Airways Cargo (Flight Number BAW 3428/13th October) / Had to return to Delhi after approx 1 1/2 hours into a flight from Delhi to Stansted. Aircraft was a 747 400 Freighter with no reported hazardous cargo on board. Strong fumes in Flight deck from Air Conditioning. QRH actioned but fumes persisted therefore automatic requirement to land at nearest suitable airport. Troubleshooting on the ground found no source of fumes. One posible suggestion put forward by engineers was that, because APU was U/S, we had had to use a Ground Air Start truck for engine start. This may have put some contaminant or other muck into the air duct. Why it took so long to develop (i.e at least an hour into flight) was not explained. ASR filed with request to be treated as MOR to CAA. The ASR was filed in the cargo area at Delhi airport after landing and I regret that I was not given a copy. In the subsequent week, one co-pilot mentioned that, like myself, he had felt "catarrhy" and feeling "thickness in the throat". Because of the nature of Delhi's Cargo area, we were not given medical checks after landing.
14-Oct-2005	BAe 146		G-CFAB / BA1717 / Oily smell was detected in the flight deck on ground with APU air selected to supply both air conditioning packs. The smell disappeared when engine air was selected and APU air was not used for the remainder of the flight. Engineering subsequently cleared the APU gearbox vent / ASR / low risk
18-Oct-2005	B767	200508672	G-BNWO / Crand Cayman. Strong burning rubber/electrical smell at 1000ft on finals. investigation could establish no aircraft related cause of the reported fumes. The aircraft operated for two months without recurrence. Non-handling pilot donned oxygen mask and monitored pilot handling, who was flying manually. Aircraft landed safely in marginal weather conditions. The operators FIM investigation could establish no aircraft related cause of the reported fumes. The aircraft has operated without repeat of the reported fumes, for two months. There have been no associated reports raised against the aircrafts air-conditioning system in that same period. On the above evidence no further action is considered necessary. CAA Closure: The hazard is adequately controlled by existing requirements, procedures and documentation.
19-Oct-2005	A319		G-EUPO / ASR / MOR / LHR-LIS / BA504. Smell lasted approximately 2-3 minutes then disappeared
19-Oct-2005	B757	200508728	See Below
19-Oct-2005	B757	200508728	See Below
19-Oct-2005	B757	200508728	CAA Pretitle : Following strong oil smell on take off during two preceding sectors, nr2 engine oil found to be overfilled by 2 litres. Investigation found incorrect procedures were used; recurrent training given. CAA Precis : Investigation found nr2 engine had been overfilled by 1 litre - drained to correct level. The engineers who worked aircraft on night shift interviewed. Incorrect procedures had been used. Apparently, the engines were run on one stand and the aircraft was then towed to another stand before the oil levels were checked. This resulted in the overservicing. Engine shut down times had not been recorded. Recurrent training has been provided. CAA Closure: The hazard is adequately controlled by existing requirements, procedures and documentation.
19-Oct-2005	B737		G-GBTB / During LUX-LGW all three cabin crew at the rear of the a/c a B737-400, reported feeling unwell specifically a sense of heavy presure on the top of their heads.The packs were put to high flow and the recirc fans turned off to no effect.These were then restored and the right pack turned off. Shortly after the crew reported feeling better. No fumes were smelt and no pax reported any symtoms. The a/c was taken out of service for investigation.

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19-Oct-2005	B737		G-DOCL / LGW-MRS / Boeing 737-400, crew noticed a smell of old socks or wet trainers during the climb something that is apparently common on the 737-500s. No ill effects were felt.
21-Oct-2005	B757		G-CPEL / BA500 / ASR / MOR / LHR - LIS / FCR / Fumes of an oily nature smelt both in the cabin & in the flight deck. The event happened late in descent at about 10,000ft. The smell did clear after the initial actions of the check list but returned later. The aircraft was flown back to LHR with the right pack selected off on advice from engineering. No further Smell. QRH checklist completed with both pilots on O2 for the remainder of the flight. Fumes were oily in nature and a slight blue haze was seen in the cabin.
22-Oct-2005	BAe 146		G-JEBD / LGW -BHD / BE 962 / During the taxi in on to stand at BHD there was a very Strong smell of Burning Paper. On last sector ABZ - BHD/ Be 118. During Approach to Land runway 22 at BHD. Fumes were apparent during the landing checks, when selecting Eng Air to APU Air. Packs swhiched Off during After Landing Checklist. APU Switched Off and DV's opened during shut down Checklist. I donned Oxy mask on the approach to land.
24-Oct-2005	B757	200508874	Manchester / CAA Pretitle : Strong chemical smell on flight deck during climb out. Oxygen masks donned for approx 2 minutes until smell dissipated. Flight continued. CAA Precis : See also 200505942.
24-Oct-2005	B757	200508808	BA1487 / ASR / MOR / GLA-LHR / G-CPEN / Following the start of the right engine and during the start of the left engine, a strong oil smell was detected by both piolts. Oxygen masks were donned / After 5 minutes, pilots came off oxygen / Both pilots felt a slight headache which cleared after a few minutes but both felt well enough to continue the flight. CAA Pretitle : Strong smell of fumes during engine start. CAA Precis : Following RH engine start and during LH engine start, strong smell of fumes noted by both pilots. Oxygen masks donned. Fumes dissipated after approximately 5 minutes. Pilots came off oxygen although both suffered with a slight headache for a few minutes. Investigation being progressed under 200305917.
25-Oct-2005	B737	200510773	G-DOCX. Barcelona. Pungent smell observed in flight deck during take off roll prior to V1. Flight crew donned oxygen masks as a precaution until the air cleared. No smell noted in the forward or aft cabins.
25-Oct-2005	BAe 146		G-FLTA / Scatsta (Shetland Islands) - Aberdeen On arrival back in Aberdeen, both cabin crew commented that there was a strong oily smell in the cabin and the ‘Number 2’ complained of a headache. She wasn’t aware that the contaminated cabin air and the headache could have been connected. The incident was reported over the phone to an engineer. Not written up. It is interesting to note that G-FLTA was involved in a more serious incident back in August 2005.
25-Oct-2005	B757		G-BPEC / LHR-BUD-LHR / Crew reported It was the first flight of the day and both smelt oil during the very initial climb out. In Budapest the left engine smelt very strongly of oil. Crew asked local engineer to call engineering in London and ask what they wanted to be done? It was suggested that the Left pack was kept OFF for the return sector and all was then OK. Engineering action: --RAISE 25OCT05 LHR BUD 01/4891/01 21009900 Q 3 D DEF: OIL SMELL.ON FLT DECK DURING TAKE OFF POWER . TRASIENT OF SHORT DURATION BUT SMELT BY BOTH PILOTS / ACT-OIL SMELL SUSPECT FROM LH ENGINE REQ BY LHR MTC LH AIRCONDITIONING PACK CLOSED A/C DIAPTCHED IAW MEL 21 51 1.

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27-Oct-2005	BAe 146	200508883	G-JEBD. BHD. Strong smell of burning (paper) on two occasions on the same day. Once during taxi-in and later during approach. First Officer donned oxygen mask on second occasion. Investigation found no fault. An inquiry was undertaken, including interviews - neither the Captain nor cabin crew recalled reporting fumes or burning at any time. Additionally, no defect was recorded in the aircraft's technical log. As a precaution, regular air-conditioning packs inspections had been accomplished with nil findings. CAA Closure: The hazard is adequately controlled by existing requirements, procedures and documentation.
27-Oct-2005	EMB145	200508907	Edinburgh (EDI) / CAA Pretitle : PAN declared due to fumes in cockpit and forward cabin. Oxygen masks donned. Aircraft landed safely with AFS in attendance. CAA Precis : While in the cruise the captain noticed a smell of burning plastic. This was confirmed by the first officer and the cabin crew reported that the smell was apparent in the first two rows of the cabin. The fumes got worse and both flight crew went on to oxygen. A PAN was declared and a direct routing obtained. The (cabin) crew were affected by the fumes, reporting light headedness and headaches. Communication was a problem with oxygen masks on as ATC could not understand the flight deck and the flight deck could not hear ATC clearly. As a result the oxygen masks had to be removed from time to time to communicate with ATC. On landing the flight deck windows were opened to vent the cockpit and communication was established with the fire service on the ground, who followed the aircraft to the stand. See also 200501219, 200504797, 200506290 and 200508412.
27-Oct-2005	B757		G-BPEC / LHR-GLA-LHR / CR & JS / CSD entered flight deck and advised aircraft stank / Left pack turned off on outbound sector / Awaiting for info / tech log entry ? / Cabin Crew Incident Form Completed by CSD stating: open entry on tech log regarding smells in flight deck prior to outbound sector.Fumes on f/deck during ascent.Cahnge of flight crew in GLA.Management captain boarded aircraft & was given full verbal & written report by departing capt. On descent into LHR CSD entered f/deck & was a ware of a very strong smell. On arrival in LHR CSD developed very strong headache & sore throat.Capt was aware of the smell but had not turned any of the packs off. CSD asked if the aircraft would continue to fly & capt relied he would leave the tech log entry open, it would be checked by engineers, but in the interim it could fly on 1 pack.
28-Oct-2005	A320		G-EUUG / BA879 / LED-LHR / ASR. During approach flight crew and cabin crew suspected oil fumes in flight deck and cabin respectively. Oil smell disappeared by 3000 feet.

30-Oct-2005	A320	200508915	G-EUPF / ASR / MOR / ABZ-LHR Return to ABZ within 18 minutes due to fumes in cabin and cockpit / BA1307 / O2 Used / At least CSD with symptoms / Fan failure suspected not oil *replace entry when this is confirmed. Crew on oxygen as felt faint/light headed. ILS and GPWS failure messages followed by fumes in forward cabin and on flight deck. MAYDAY declared and oxygen masks donned. Aircraft returned and landed safely. AAIB AARF investigation. AAIB Bulletin 2/2006, ref: EW/G2005/10/22 - Summary: Following take off from Aberdeen, failure messages related to ILS and GPWS illuminated and the cabin crew became aware of a smell in the forward cabin area. The strange smell then became evident on the flight deck and there was an increase in cabin temperature. The flight crew donned their oxygen masks, declared an emergency and returned to Aberdeen. After landing, the smell had dissipated. On the previous flight, ILS 1 and the pressurisation system were not working correctly and after landing the 'AVIONICS VENT SYS FAULT' message appeared on the engine and warning display. After the event, it was suspected that the problem lay with the avionics cooling system, so the avionics vent fan and filter were replaced. There was no repeat of the strange smell on subsequent flight sectors. Examination revealed noisy and worn bearings. The avionics vent fan manufacturer has issued a Vendor Service Bulletin 3454-21-108, which replaces the current steel ball bearings with an improved type utilising ceramic ball bearings. The aircraft manufacturer has issued a service information letter (SIL 21-141) which notifies aircraft operators. CAA Closure: The hazard is adequately controlled by the actions stated above.
31-Oct-2005	A319	200508982	LHR / CAA Pretitle : Cockpit air contamination - suspected from engine oil via bleed system. CAA Precis : During descent the first officer detected an oily smell in the cockpit, which lasted approx 20 secs. The smell was not detected by the captain at this time but, at 1000ft QNH on final approach, the smell returned and was apparent to both flight crew. The smell disappeared approx 30 secs to 1 min after landing but returned as the aircraft arrived on stand. No ill effects were noted by the flight crew and the smell was not noticed in the cabin. See also 200507196. NOTE: CAA Precis failed to mention crew comment: 'Oxygen not used due to late stage of approach and workload'.
1-Nov-2005	B757		G-BPEC / LHR-FCO / Transient fumes in flight deck / Tech log signed off to report next sector
1-Nov-2005	B757		G-BPEC / FCO-LHR / Transient fumes in flight deck again as per previous sector / Tech log entry / Captain advised aircraft would be taken out of service / Aircraft found to have an APU oil leakage problem and APU was replaced.
2-Nov-2005	B757		G-CPEM / Following a brief (transient) fumes event last night on departure and following extensive discussion with both the First Officer and CSD to confirm the nature and longevity of the smell I did not believe it necessary to divert the aircraft. However full details were written in the aircraft technical log (G-CPEM). BUD-LHR 2nd NOV

7-Nov-2005	B757	200509210	CAA Pretitle : Engine oil fumes on flight deck. CAA Precis : A strong smell of engine oil was apparent as soon as the APU was switched on and throughout the flight. The smell became worse once the engines had been started and even stronger as the thrust levers were advanced during the take off roll and subsequent climb. During the cruise, at lower power settings, the smell subsided but at top of descent, as the levers went to idle, the smell increased and remained throughout the descent. An attempt to fault find by turning off the air packs in turn failed to isolate the source. On arrival it was established that the vestibule area on the other side of the flight deck door had no fumes, which are believed to be confined to the flight deck. The crew reported being aware of the fumes throughout three sectors and described symptoms such as dry/sore throat, dry/stinging eyes and nausea. The smell was confirmed by an engineer and a tech log entry was made. See also 200501820.
8-Nov-2005	B757	?	See Below
8-Nov-2005	B757	200509209	G-BMRD / East Midlands Airport. Oil fume contamination. Investigation confirmed that this was caused by over-filling of the oil reservoirs. Following a crew report of oil fumes in the air conditioning on the inbound sector, engineers ran the APU and packs, confirming a constant smell of fumes. Both engines were run for several minutes, the fumes being the most noticeable from the LH pack running. Both crew members, by that time, were suffering from stinging eyes and were stood down for the remainder of the night, being declared unfit. Investigation confirmed that this was caused by over-filling of the oil reservoirs. Filling/servicing instructions have been revised and a placard has been added to the service panel to assist in raising awareness of the problem. CAA Closure: The hazard is adequately controlled by the actions stated above.
9-Nov-2005	EMB145	200509462	CAA Pretitle : Fumes noted in flight deck following engine start, which appeared to dissipate during taxi. Fumes returned in flight deck and cabin during cruise, descent and landing.
9-Nov-2005	B757	200509282	G-BPEC / ASR / MOR / BA911 / CAA Pretitle : Noticeable level of oily fumes in flight deck from rotation to 2000ft during initial climb. No adverse effects felt by flight crew. CAA Precis : See also 200507355.
10-Nov-2005	A320		BD108 / AMS - LHR / 14.35 GMT / G-MIDP / Tech log ref 077859/1 / Summary: Strong smell of 'oily mist' experienced on flight deck during Climb and descent. Event and Cause: During take off and initial climb a strong smell appeared in the cockpit (not in the cabin) of 'oily mist / sweaty socks.' The smell cleared after 10 mins. Again during the descent as flaps and gear extended the smell returned but less strong as before. Note: Flight continued to destination, No Oxygen used by flight crew. (with hindsight we should have used Oxygen as we do not know the implications of the smell, or how long it would last). We do not have any guidance from bmi on this issue....it would be nice to have an update to our SOP's from BMI, so that we don't feel 'pressured' to continue the flight, in difference to BALPA recommendations. Its a difficult call to make during a flight to don oxy masks and divert, just for a 'smell'.
11-Nov-2005	B734	200509332	SEE incident below of 12/11/05 / G-DOCL

12-Nov-2005	B734	200509332	ASR / MOR / TECH LOG REF 04/4624/01/ G-DOCL / B737-400 / Aircraft had contaminated air smell on 11 Nov 2005 (see above) during take off and entered into tech log but 'No fault found' and re-entered into service on 12 Nov 2005. Same crew who over 3 sectors traced fault to number 2 engine bleed air / Crew stated that crews should not be exposed to contaminated air due to engineering not providing rectification to a previously reported fault. Symptoms of exposure not reported in ASR. MADRID / CAA Pretitle : Contaminated bleed air on take off for two consecutive days. CAA Precis : Two sectors were flown by the reporter the previous day in which bleed air contamination was noted on two take-offs. Overnight engineering investigation failed to identify a cause. On the subject flight, the source was identified as nr2 engine bleed air. NOTE: CAA Fail to mention crew effects
14-Nov-2005	BAe 146		G-OZRH / CDG-BHX / ASR / In descent passing 4000 ft with thrust levers at flight idle a distinct smell was noticed like old socks / wet dog. The source of the cabin air was changed from engine to APU and the smell quickly dissipated.
15-Nov-2005	B757		G-CPER / LHR-DUS / ASR / BA936 / Parked / BA Ref: 262612 / During turnaround the aircraft filled an intense smell of plastic/solvent, similar to formaldehyde. Event occurred shortly after the cleaning crew had left which led to the belief that cleaning fluid was the source. Cabin crew established that this was not the case. Flight crew and engineer continued faultfinding and inhaled a lot of the fumes. Source traced to APU. Sector operated with APU bleed isolated.
15-Nov-2005	D328	200509404	Pretitle : Anti-collision lights failed and smoke in cabin during taxi out. Aircraft shut down and passengers evacuated on taxiway. No reported damage or injuries. AAIB Field investigation. Precis : AAIB Bulletin 3/2006, ref: EW/G2005/11/04 - Summary: The aircraft was taxiing for takeoff at London (City) Airport when ATC informed the commander that their anti-collision lights were not illuminating. Shortly afterwards the flight crew identified that the associated circuit breaker 'popped' whenever the lights were selected ON. Meanwhile, the cabin attendants reported that the cabin was rapidly filling with smoke. An uneventful evacuation of the aircraft was carried out with no injuries to any of the crew or passengers. The investigation concluded that the crew experienced two unrelated faults and that the smoke in the cabin most probably resulted from leakage of oil from the LH engine into the LH Environmental Control System pack. CAA Closure: No CAA action appropriate.
15-Nov-2005	BAe 146		FlyBe / Bordeaux - Fumes -

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18-Nov-2005	BAe 146	200509563	G-CFAE / LCY-GVA / LHS Pilot flying level at FL310 in VMC at night, cabin crew advised the aircraft Commander that all three cabin crew and a passenger at the rear of the passenger cabin were all suffering varying degrees of 'dizziness' and 'lethargy'. It is stated that oxygen was administered to CC2. The Co-Pilot reported feeling unwell after the flight, when medical attention was sought by all the Crew. Line Engineering report finding no causes when completing post incident procedures in BAE SIL 21-45. However, after a ferry flight to a Company Maintenance facility, oil was found leaking from an unidentified engine bypass, indicative of a leak from #9 bearing. This bearing pack was replaced prior to further release to service. CAA Pretitle : Cabin crew illness/incapacitation. Cabin air quality suspected. CAA Precis : During cruise at FL310, all three members of the cabin crew reported feeling unwell/uncoordinated and dizzy. A diversion was considered but it was decided that continuation of the flight to planned destination was the best option. Later in the approach it was reported that a passenger was unwell at the rear of the aircraft and following completion of the post flight checks the P2 also reported feeling unwell. No affected person was able to sense, smell, taste or identify what the problem could be. All crew visited a hospital and following extensive checks were found to be satisfactory.
19-Nov-2005	B757		G-FCLK / ALC-MAN / TCX361L / ASR / cn 26161/557 / Boeing 757-2Y0 Smell was very strong on Capts side, it was a smell of fuel which seemed unusual. The smell occurred on the inbound sector and appeared in spells, until the descent where it became stronger. The Capt felt a bit dizzy and then I had tightness of forehead which he agreed he had too. Both of us went onto oxygen, tech log was filled in and an ASR form has been filed.
20-Nov-2005	B757	200509614	G-BPEK / ASR / MOR / Strong oil smell in climb / LHR-EDI / Return to LHR due to emergency being declared at 20000ft / O2 Used / Both pilots had physiological symptoms of headache and cold tingling feeling on the skin. CSD confirmed smells. P1 effects 24 h later / Both pilots took next day off / Manager said: 'no worse that car fumes' /
21-Nov-2005	Q400	200509637	G-JEDL. CAA Pretitle : Suspected oil fumes on flight deck. CAA Precis : Several minutes after levelling in the cruise, both pilots noticed a hot, oily odour. The reporter notes that the aircraft was operating with a priority bleed off due to a known crack in the engine compressor strut. Emergency checklist actions for smoke were commenced but before the crew went onto oxygen the smell started to dissipate. The crew then reconfirmed that the priority bleed was off and called a cabin attendant to the flight deck to verify that the fumes had cleared. The aircraft continued to destination with no further problems. Incident reported to engineers on arrival and tech log entry made. Nr1 engine subsequently replaced.
24-Nov-2005	SF B587340	200509980	CAA Pretitle : Shortly after selecting HP bleeds 'ON' for the boot test, a strong acidic smell became apparent in the flight deck and cabin. Aircraft returned to stand and passengers disembarked.
25-Nov-2005	A319	200509861	G-EZDC. Stansted. Toxic fumes apparent on flight deck from approx FL160. Captain elected to go onto oxygen until just before touchdown. Investigation resulted in APU replacement. Nil problems reported since. CAA Closure: The hazard is acceptable provided the frequency remains low.
25-Nov-2005	B757		G-BPEC / ASR / MOR / LHR-MAD / BA 459 / Fume intensity suffecient to cause both pilots to use O2 until smell disappeared / Only flight deck affected / On arrival engineer found both engine oil levels had been overfilled /

29-Nov-2005	B757	2000510814	G-BPEO / LHR-GLA / Transient Fumes / No O2 / Tech Log Entry 03/2878 / Oil leak found / No 1 pack Locked Out for return sector to LHR. Cabin crew reported acrid/pungent smell during take off and initial climb, giving rise to physical symptoms. The cabin crew reported an acrid smell on take off, in particular from doors 2 to 4. During this time there, was a slight smell of "scorched oil" on the flight deck. The cabin crew also suspected a slight haze in the cabin. Duration of the event was 8 minutes. The cabin crew (and positioning crew) reported a metallic taste in the mouth, stinging eyes and headaches. Symptoms began to subside after 30 minutes. The captain advised the crew to seek medical attention if the symptoms persisted on landing. Investigation found evidence of oil leakage from the LH engine forward bearing housing service tubes - associated seals replaced.
29-Nov-2005	B757		G-BPEO / GLA-LHR / ASR / MOR / No O2 / Tech Log Sector 2879 / Cabin crew all suffering effects even with left pack inop. See previous sector.
30-Nov-2005	DHC8	200509817	G-BRYY. SOU.Cabin temperature excessively hot followed by smoke/fumes after nr1 air conditioning pack switched off. Jamming of Pressure Control Valve (PCV) suspected. The cabin temperature was reportedly too hot with the cabin indication showing 40deg and did not change in either auto or manual. Nr1 air conditioning pack was switched 'off' and after approx three minutes smoke was reported in the cabin, although there were no warnings on the CWP. The QRH was consulted and the flight continued to destination where an uneventful landing was carried out five minutes later. Engineering ground runs carried out and the air conditioning pack was controlling in both auto and manual. The reporter suspects that the fault was caused by a jammed PCV. See also 200502402.
1-Dec-2005	Q400	200510221	G-JEDR. Exeter / CAA Pretitle : Strong burning smell on flight deck. Aircraft returned. CAA Precis : Climbing through approx FL70 a strong burning smell was noticed on the flight deck. No warning or caution lights were seen and initially nothing could be smelt in the cabin. After priority bleed was selected 'OFF' the cabin crew reported that a burning smell was now apparent in the cabin and a short while later the toilet smoke alarm sounded. No smoke was seen at any time but as a precaution the aircraft descended and returned to base. The smell subsided in the descent and did not recur. Bleed tests had been completed after start as per SOPs and the aircraft had taxied with bleeds on without any abnormalities.
2-Dec-2005	BAe 146	200509982	G-JEAY / LGW - BHD Techlog Ref No 152439/1 / Aircraft Stunk right from the off BAe WET DOG with SWEATY SOCKS, So I knew it was going to be a bad day. Did not feel too bright after sector 2 not too bad on sector 3 and had Screaming Headache during the climb out, the worst I have ever had in flight on last sector. Felt like someone drilling through my forehead above my left eye and out the back of my head. I went on OXY at the top of climb and stayed on OXY for the rest of the flight. Captain acknowledged there was a CAQ issue and entered the details in the Techlog, I filed an ASR/MOR and CAQ report. I had the Moon Walking as I disembarked the Aircraft and on the way back to the Crew Room, very Odd! 2 Cabin Crew noted that my Complexion was Flushed and one who was an EX BA guy commented that my Hands were an unusual colour which I had not noticed.
2-Dec-2005	B757		G-CPER / ASR / MOR / LHR-BUD / BA868. During boarding a strong 'electrical smell' reported by flight crew and cabin crew at door 1, 2 and 3. A precautionary evacuation was carried out. Enginner thought the APU had been the source of the problem

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2-Dec-2005	A320	200509977	G-EUUJ / LHR-MUC / BA950 / ASR / MOR / Oily fumes after take off / No oxygen used / CAA Pretitle : Oily fumes detected on flight deck. CAA Precis : The captain became aware of oily fumes on the flight deck just after take off. The fumes cleared after approx two minutes and were not detected by the first officer. The cabin crew reported a smell of "cleaning fluid" in the rear galley for about four minutes after take off. No ill effects were reported by any crew members. Engine oil quantity was normal and there was no evidence of any oil leaks. The fumes were attributed to de-icing fluid. NOTE: CAA Summary did not mention: 'On verge of ordering oxygen when smell disappeared.'
4-Dec-2005	B757		Fume event - G-BYAT
5-Dec-2005	B757		Fume event - G-BYAI
5-Dec-2005	BAe 146		*** DATE IS BETWEEN 5-12 DECEMBER 2005 - NEEDS TO BE CONFIRMED *** / BA1806 / BHX-CDG / G-CFAH / RJ100 / Flight Crew report noticing 'Sweet Oily' smell following changeover from APU air to engine air. All 3 CC also noticed smell / 1 CC felt tight chested and another felt momentarily 'light headed'.
7-Dec-2005	BAe 146	200510045	HB-IXQ. Zurich. AAIB Initial Notification: Smoke on flight deck and in cabin after air source changed from APU to engines. Emergency declared. Aircraft returned. Subject to investigation by Swiss Authorities. Nr1 engine bleed air switched off during return and aircraft landed safely.
7-Dec-2005	BAe 146	200510097	Southampton / CAA Pretitle : AAIB Initial Notification: Acrid fumes in passenger cabin during taxi out. All three cabin crew and five passengers affected by fumes. Subject to AAIB AARF investigation. CAA Precis : During taxi with APU air selected on all three cabin attendants and some passengers noticed strong acrid fumes in the cabin. All three cabin attendants felt dizzy and nauseous and one then was physically sick. The P1 was informed and the aircraft taxied back to stand with the APU air selected off and the engine air selected on for 4-5 minutes. No fumes were apparent on the flight deck. After engine shut down and passenger disembarkation, one of the cabin attendants was still physically sick and unable to perform her duties. All three cabin attendants were taken to hospital for tests iaw the 'BAE146 Notice to Aircrew 42/05 (17 Nov 2005)'. The reporter comments that the aircraft had been de-iced in the morning and confirms that not only was this the fifth sector of the day for this aircraft, but also the crew's third sector of the day on the same aircraft.
9-Dec-2005	BAe 146		G-JEBE. Fumes during climb out on first sector of burning newspaper, neither Captain nor Jump Seat member could smell anything. Fumes again on 3rd sector but this time of burning rubber, again captian said that he could not smell anything. Aircraft swap on last / 4th sector to G-JEBA. On entering flight deck a strong smell of fumes was apparent. P2 open both DV windows and turned off both packs, selected manual and cool after 5 minutes. Fumes continued to be apparent throughout allphases of the flight. None of the other crew members could smell anything on this sector. However both the No1 and No3 Cabin Crew said that they felt nauseous, light headed and mild headache during climbout and cruise on sectors 1 and 3.
10-Dec-2005	B777		BA2026 / G-VIID / B777 LGW BASED / Chemical smell during descent into LGW: Chemical / plastic smells were noted by the flight crew in the cockpit, and the CSD in First class galley during descent for around 5 minutes. ACTION: Flight crew asked CSD to investigate this in other cabins. He confirmed that no cabin crew were using any chemical agent. Flight crew discussed use of oxygen masks, but as smell dissipated, no further action was taken

11-Dec-2005	B757	200510775	G-BPED. LHR. Captain temporarily donned oxygen mask as precaution against extensive smoke over London associated with oil depot fire. No fumes apparent on flight deck.
11-Dec-2005	B777	200510774	G-VIIG. LHR.Flight crew donned oxygen masks when P2 felt unwell after having flown through smoke over London associated with oil Depot Fire.See also 200510775.
12-Dec-2005	EMB145	200510297	Suspected contamination of cabin air. During the early stages of the first of four sectors, the Captain noticed a faint smell on the flight deck, which appeared to dissipate after about five minutes. During the third and fourth sectors, with the Captain handling, the First Officer drew his attention to a number of operational errors, including missed calls and a misjudged descent profile. Initially the errors were attributed to tiredness, however, the next day the Captain began to experience symptoms including headache and severe fatigue, which lasted a further two days. The reporter therefore suspects that the smell on the flight deck and the subsequent symptoms may have been the result of contamination of the cabin air supply.
13-Dec-2005	B757		Fume event - G-BYAI
13-Dec-2005	B757		Fume event - G-BYAI
13-Dec-2005	A319	200510579	G-EZIB. Prague. Nr1 engine surge/stall together with rapidly increasing engine vibration indication and burning smell on flight deck. Take off rejected. During low speed taxi after landing, a pronounced burning like smell was noticed on the flight deck and in the cabin. Smell initially dissipated during taxi to stand but returned slightly when thrust above idle. The engines were visually inspected during turn-round and no damage was evident. Liaison with engineering (NMC) resulted in a normal dispatch for the next sector. Engine start was normal. During the taxi out, the smell returned. At hold the engines were run-up individually to approx 35% N1 and it became evident that the nr1 engine was creating the smell, however as all engine parameters were normal the decision was made to continue with the decision to take off. On the R/W with approx 50% N1 all parameters were normal, however some surging/stalling noise was noticed. The thrust levers were advanced to FLEX/MCT and the take off commenced with parameters normal. Vibration from the nr1 engine was seen to be rising rapidly (3.5 > 4.0), the take off was rejected and a very loud surging/stalling noise became evident having selected reverse. Reverse cancelled and aircraft returned to the stand.
13-Dec-2005	EMB145		Air Conditioning Fumes. The a/c was anti-iced overnight. Prior to departure the APU was used for air conditioning without incident. On taxi-in at BRU the APU failed to start. The QRH was followed and it started on the second attempt. When the APU was then used for air conditioning with Pack 2 there was immediately light fumes in cabin and flightdeck. The Pack was switched off and the pax disembarked. Afterwards, Packs 1 and 2 were tried again with the same result. The following flight was operated without using it for air condition. Engineering at EDI found evidence of de-icing fluid in the APU.
15-Dec-2005	B757		Fume event - G-BYAI

18-Dec-2005	BAe 146		G-JEAM / ASR / There were complaints from 2 passengers on the last sector BHX - BHD. They said that the aircraft continually smelt like a "Deep Fat Fryer". They also reported that there was a strong smell of fumes during the "Push Back" off stand at BHX and throughout the Climb. I have operated this aircraft for the last 5 days and can confirm the continuos "Deep Fat Fryer" Odour. We had an "Alt Bust" on approach to BHD. We mis heard instructions for another A/C with similar call sign. However, we had continual call sign confusion and continually mis heard instuctions throughout the cruise and descent. The Altitude Bust was not Filed by ATC as there was no conflict.
18-Dec-2005	A321	200510799	G-OOAF. Rovaniem. Fogging in cockpit and cabin during landing run. Runway conditions were 5mm of ice treated with sand and an outside air temperature of -10deg C. Late in the landing run, as reverse thrust was cancelled, fogging was noted in the flight deck and cabin, which the flight crew considered to be runway deposits being drawn into the aircraft. During a subsequent external check of the aircraft, the pattern of dirt around the engines also suggested the same theory. The packs were run full hot to clear contamination. An engineer carried out a visual inspection of the aircraft with no further action required.
20-Dec-2005	SF 340	200510493	G-LGNC. GOW. Acrid odour on flight deck during descent and landing. During descent through 6000ft, an acrid odour was detected on the flight deck that persisted for approx five minutes. No smoke was detected so masks and goggles were not donned although both flight crew members commented on a sore dry throat and sore eyes on landing. No odour was evident in the cabin but odour was still present on the flight deck after landing.
20-Dec-2005	B777		ASR / G-YMMB / BA094 / YUL-LHR On approach to LHR, passing 3000 a bad smell arrived on the flight deck. Smell still present after landing. One crew member physically sick.
23-Dec-2005	EMB 145	200510514	G-EMBI. En Route. Smell of fuel noted in cabin during the cruise, which progressively increased during flight. Aircraft descended below FL250, nr2 pack turned 'off'. Smell dissipated by landing.
23-Dec-2005	EMB145	200510514	200510493
24-Dec-2005	B757		Fume event - G-BYAR
24-Dec-2005	A320	200510763	G-BUSC. LHR. Precautionary crew disembarkation (no pax on board) due to acrid smoke and electrical burning smell. After the ground air conditioning cart was disconnected the smoke ceased and slowly dispersed.
25-Dec-2005	B757		Fume event - G-BYAR
25-Dec-2005	B757		Fume event - G-BYAR
26-Dec-2005	B757		Fume event - G-BYAR

26-Dec-2005	B737	200510730	G-CDZN / Doncaster- Sheffield. Alleged poor air quality at the rear of the cabin. When passing FL100 during the climb, cabin crew at the rear of the aircraft reported feeling light headed and dizzy. All pressurisation and bleed controls checked and confirmed to be functioning normally. There was no report of anything unusual from the passengers. The flight continued but, later, the cabin crew again reported "feeling light headed and heavy limbed" especially towards the rear of the cabin. As the aircraft was close to the top of descent, the flight continued to its planned destination. During the return flight, an empty ferry, the crew were positioned at the front of the cabin with therapeutic oxygen available. One crew member went to the rear of the cabin and reported the same symptoms. At no timewere there any unusual smells or smoke / fumes. Pressurisation was normal throughout and no symptoms were observed from the flight deck crew. Floor grills subsequently cleaned, recirculation filters replaced and engine runs carried out with no further reports. The operator initiated a B737 fleet check with no similar problems noted.
26-Dec-2005	A330	200510519	G-OJMB / Lavatory smoke detector tampered with (blocked). During the cruise it was discovered that a lavatory smoke detector had been blocked with a sick bag and there was a smell of smoke in the lavatory. It was not possible to identify the culprit but all passengers were reminded of the smoking ban and lavatory use was monitored for the rest of the flight.
27-Dec-2005	B757		Fume event - G-BYAR
27-Dec-2005	Q400	200510566	G-JEDN. En-route. Fumes inside aircraft. During pushback, fumes became apparent in the cabin but disappeared when the aircraft turned onto the runway. During flight, when bleed air was switched on, the fumes returned and remained present for the rest of the flight. After landing, an engine ground run was carried out and the fumes were reproduced. A cabin attendant described the fumes as very unpleasant and reported feeling sick during the flight and tired/lethargic afterwards. The fumes were again present during the return sector but did not appear to be as strong. The reporter also notes that there were significant difficulties in controlling cabin/flight deck temperatures, as well as problems with the intercom and PA systems. See also 200408810 (same aircraft).
28-Dec-2005	B767	200510597	G-BNWW. Brindisi. Electrical burning smell on flight deck. Forward equipment cooling fan failed. Flight crew donned oxygen masks. Aircraft diverted to Rome and landed safely. Subject to Italian authority investigation.
28-Dec-2005	B747-400	200510520	G-CIVY / CDF / AAIB Initial Notification: MAYDAY declared due to fumes in pax cabin. Flight crew donned oxygen masks as a precaution. A/c diverted to Cardiff. AAIB AARF investigation. AAIB Bulletin 05/2006, ref: EW/G2005/12/17 - Summary: The aircraft was inbound to London Heathrow Airport when, prior to descent, the cabin crew reported a smell of burning and a haze in the cabin, initially in the area of the first class galley but spreading throughout the whole lower deck. A precautionary diversion to Cardiff was carried out without incident, whereupon substantial food spillage was found in the galley ovens and this is considered to have been the likely source of the smell and haze. CAA Closure: No CAA action appropriate.

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28-Dec-2005	A319	200510696	G-EZKA. NCL. AAIB Initial Notification: PAN call due to smoke in flight deck and cabin. A/c returned. PAN cancelled but medical assistance requested for pax affected by smoke. Subject to AAIB AARF investigation.
28-Dec-2005	B737		PPRUNE / NCL-NCL / Captain comments: 'Very heavy snow contamination on whole a/c needing extensive de-icing. Full power bleeds off takeoff using apu air for initial climb. Due to high angle of climb and very large amount of residual fluid on fuselage, the contaminent entered the APU intake in unusually large amounts. This manifested itself as thick acrid black smoke in the cockpit at about 500\` agl requiring cockpit masks to be donned. Similar smoke in the cabin confirmed that this must be an air conditioning issue so re-configuiring the bleed airs instantly solved the problem. Bit dodgy for a bit though when it all happens at max t\o wt at 500\`!' Landing afterwards became interesting due to lack of available places to go. Lots of pax complained of throat/eye problems in the air but were ok when offered medical attention. AAIB report:Prior to the flight the aircraft was de-iced due to snow accumulation. During a 'No Engine Bleed Air Takeoff', in which APU bleed air was in use, fumes and smoke entered the cockpit and cabin causing some passengers to suffer from eye and throat irritation. After isolating the APU bleed air and selecting engine bleed air the fumes dissipated. The aircraft returned to Newcastle and the passengers were offered medical attention. The fumes were as a result of de-icing fluid entering the APU air inlet during the initial climb out. (Not on CAA MOR database)
28-Dec-2005	Dash 8		BHD-BHD / G-JECF / Contaminated Air filled Cabin and Flight Deck after Take Off / SOU - BHD / BE996 / Multiple crew effects with crew going to Hospital on arrival at Belfast / O2 not used / ASR / Visible Misting / Cabin crew light headed and peripheral visual problems /
29-Dec-2005	A319		G-EUPD / ASR / LHR-LHR / BA1308 While taxiing for third sector a strong smell of hot electrics observed in the flight deck. A smell was also noticed during second sector from NCL, but after diagnosis was attributed then to chemical de-icing. Cabin crew later mentioned smell observed when they boarded the aircraft, but vfailed to inform crew. Aircraft returned to stand. 2 hours later smell still present so aircraft removed from service.
30-Dec-2005	HS 125	200510628	G-OLDD. SEN. AAIB Initial Notification: Smoke on flight deck. Crew donned oxygen masks. MAYDAY declared. Landed safely. Subject to AAIB AARF investigation.
30-Dec-2005	A340	200510654	G-VGOA. LHR. AAIB Initial Notification: PAN declared and aircraft returned due to smell of burning/light haze in cabin. Aircraft held for 40 minutes to jettison fuel. Subject to AAIB AARF investigation.

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30-Dec-2005	A319	200510671	G-EZEG. Birmingham. AAIB Initial Notification: Smoke in rear of cabin. PAN declared. Fumes in cockpit & forward cabin. Flight crew donned oxygen masks. QRH actioned, PAN declared & a/c diverted to East Midlands. AAIB AARF investigation. AAIB Bulletin 5/2006, ref: EW/G2005/12/20 - Summary: The aircraft diverted to East Midlands Airport following reports of fumes or smoke in the cockpit. The subsequent engineering investigation could find no evidence of smoke or burning nor identify the source of the fumes. CAA Closure: No CAA action appropriate.
30-Dec-2005	BAe 146		ASR / MOR / G-JEBA / BE 966 / P2 on O2 / Strong fumes on switch from APU to Engine air during climb, lasted aprrox 30 seconds / P2 Headache & sore throat / Fumes again during approach during checks on switch over from engine air to APU air.
31-Dec-2005	B757		Fume event - G-BYAT
1-Jan-2006	B757		Fume event - G-BYAR
2-Jan-2006	EMB 145	200600006	G-EMBG / SOU. During initial climb, burning smell on flight deck and in cabin. Flight crew donned oxygen masks. PAN declared. Aircraft returned. Shortly after take off, a burning smell was noted on the flight deck and subsequently reported from the passenger cabin. The flight crew donned oxygen masks, declared a PAN and carried out the QRH drill for air conditioning smoke. The aircraft returned and landed safely with the AFS in attendance, by which time the smell had cleared. A cabin attendant reported feeling unwell with tingling in the fingers
3-Jan-2006	B757	200600285	G-OOOX / Tenerife.Very strong smell of oil on rotation. Oxygen masks donned. On removing masks at 4000ft, the smell had cleared and did not recur. Prior to departure, oil stains had been noted on RH engine cowling.
4-Jan-2006	A320	200600226	G-BUSB / BA1465 / EDI-LHR / ASR / MOR At approximately 2000 feet after take off, an ECAM "Smoke lavatory smoke" warning occurred, but disappeared after approximately 5 secs. First officer could smell slight trace of unusual odour, but it did not smell toxic or of smoke. Also noticed by cabin crew at door 2. Smells disappeared after that. Aircraft had been de-iced at EDI included in the report to CAA.
5-Jan-2006	Dash 8		Flight No was BE729 / G-JECG / Awaiting Details
6-Jan-2006	B777		BA298 / ASR / G-YMMK / ORD-LHR / Cabin Air - Passengers and crew felt unwell. After approximately 4 hours airborne four passengers and four cabin crew felt unwell. Two passenger fainted. Cabin crew members felt dizzy and disorientated. Recovered later in the flight.
10-Jan-2006	B735	200600223	G-GFFB / ASR / MOR / LGW-NCL / Moderate smell of engine oil fumes from take-off until 10,000 feet. A 'trace' of the smell returned whilst flying level in the descent at 15,000 feet and intermittently further in the descent. Cabin crew and passengers did not report anything and it was decided that it was not serious enough to warrant donning oxygen.
12-Jan-2006	BAe 146		BE 966 / ASR / MOR / P2 used O2 due contaminated air suspected /

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12-Jan-2006	BAe 146	200600197	G-JEBF / ASR / MOR / CAQ / BE 966 / LGW - BHD / Odour of Sweaty Socks apparent on entering first flight of day. No other Odours or Smells apparent on any of the 4 sectors operated. During cruise of last sector First Officer had symptoms of Contaminated Air. However, no fumes or smells were apparent. Reporter suspects elevated levels of CO and TCP as both these gases and chemicals are odourless and tasteless. F/O Suspended due to 5th reported incident in the previous 5 week period.
13-Jan-2006	B757		Fume event - G-BYAS
17-Jan-2006	ATR 42	200600332	G-WLSH. CDF. Smoke in cabin. During taxi in from a training detail the supernumerary (SNY) crew reported smoke in the cabin, which migrated onto the flight deck. Aircraft parked on stand and shutdown with AFS attendance requested. SNY crew reported that the smoke had come from beneath the overhead lockers at the front of the cabin and quickly spread throughout the cabin.
22-Jan-2006	B757		Fume event - G-BYAL
26-Jan-2006	B757		Fume event - G-BYAT
28-Jan-2006	A320	200600688	G-SSAS / Tenerife. On shutdown thick smoke was seen issuing from the flap fairing above the nr2 engine, which persisted for several minutes. Following consultation with Maintrol and local engineering a dry crank and idle ground run was carried out with no evidence of smoke. Flaps were also cycled. Flight continued uneventfully.
28-Jan-2006	B734	200600673	G-DOCA / LGW-PSA Return LGW / Company Ref: 268849 / The aircraft made an airborne return when a smell of oil became apparent in the flight deck during taxi, take-off, descent and cruise. A power run was carried out after landing and the smell was confirmed as coming from the left engine with an engine oil smell at 90% N1 after approximately 30 seconds. Reverser halves were opened and evidence of oil was found around VSV ring. Boroscope confirmed oil puddling from booster stator vanes to VSV's. Engine change required. Oil smelt on flight deck. Aircraft returned. A "sweet, chemical, oily" smell was noticed on the flight deck during taxi. The smell had gone by the time take off clearance was received but reappeared during take off, initial climb and again on final approach when the aircraft returned. Both bleeds were switched 'off' during taxi and the smell disappeared. The crew were unaffected by the smell. A power run was carried out and it was confirmed that there was a smell of engine oil coming from the LH engine after it had been running at 90% N1 for approx 30 seconds. The reverser halves were opened and evdence of oil was found around the variable stator vane (VSV) ring.
29-Jan-2006	B757		Fume event - G-BYAS
29-Jan-2006	B757		Fume event - G-BYAS
29-Jan-2006	A300	200600760	OO-DGL. Brussels. Smoke from E and E bay. Whilst carrying out a scheduled weekly inspection a sudden bang was heard from the E and E bay and the ground warning horn began to sound continuously. The E and E bay hatch door was opened and copious amounts of smoke billowed out. The external power switch was turned 'off' and an internal inspection of the bay was carried out with no evidence of fire. The reporter suspected that the cause of the ground warning horn and smoke might have been related to the avionic main vent fan, but when it was replaced it made no difference. Wiring found shorted and burnt.
30-Jan-2006	EMB145	200601450	G-EMBJ / Abnormal burning rubber smell evident in the flight deck.

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1-Feb-2006	SF340	200601031	G-GNTB / Acrid burning smell in the cabin. After pushback and during start checks, cabin crew reported a strong smell of burning in the cabin. Moments later, the smell also became apparent in the flight deck and the crew's eyes started to water. The engines were shut down and fire assistance requested. The fire service confirmed no visible signs of fire but a precautionary evacuation onto the taxiway was carried out. The flight deck recirculation fan was subsequently replaced. See also 200510493.
1-Feb-2006	Bae 146	200600814	AAIB Initial Notification: First Officer became incapacitated during climb. Oxygen administered. Aircraft returned. Subject to AAIB AARF investigation. Prior to becoming incapacitated First Officer reported an unusual smell, although no other crew member could smell anything. Initial investigation suggests APU oil cooler matrix was leaking into air system. See also 200402057.This Last MOR Ref Number cannot be found?
2-Feb-2006	B757		Fume event - G-BYAS
2-Feb-2006	B757		Fume event - G-BYAS
2-Feb-2006	BAe 146		ASR / MOR / G-JEBA / BE973 / The First Officer was the handling pilot. We departed runway 22 as per the brief, and turned off the noise abatement track under radar headings from Aldergove. Crew were given a climb to a flight level, and instigated the climb checks. Shortly after P2 asked if P1 could smell anything – to which he replied 'no'. P2 described it as a smell similar to that from a central heating boiler, but P1 couldn't sense anything. We were transferred to Scottish control who gave us further climb. P2 then said his throat was dry, and soon after complained that his eyes were burning and he started to rub them. P1 offered to fly the aircraft, and P2 gave me control. P1 asked if P2 was ok to continue or did he want to return to BHD, P2 said he should be OK. In the next few minutes P2 then said his fingers were tingly, and asked if I P1 very hot. P2 said if anything he was cold! When P2 leaned forwards he was sweating profusely, and his shirt was sticking to his back with the sweat. P1 suggested he took some Oxygen, and said he was returning to Belfast. P2 found it difficult to comprehend what P1 was asking, and started to read checks, but wasn't sure why, or what checks to read. P2 was conscious throughout, if incoherent.
2-Feb-2006	A319	200600825	G-EZEF / Smell of burning plastic from door 1L during take-off. Aircraft returned. On take-off a smell of burning/melting plastic was evident causing foam around crew station door IL. P1 advised and aircraft returned for a precautionary landing with emergency services in attendance.

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2-Feb-2006	B757	200600801	G-CPEN / BA952 / LHR-MUC / ASR / MOR / Accident Dangerous Occurrence & Environmental Incident Report / In-Flight Cabin Crew Incident Report Form / Tech log reference: 03/2983/01. Contaminated air smell after engine start into a headwind, during take off and in climb. O2 not used as occurences 'appeared' brief and cleared etc.... No smells noticed during remaining flight. Cabin Service Director (CSD) reported 4 cabin crew during taxi / climb felt 'very drowsy and sleep - unusual during the day. All of business class were asleep on taxi / flight and many in the rear of the cabin asleep.' When engineering investigations opended APU cowlings, oil poored onto the apron suggesting an APU oil leak. Company then said: 'APU was Ok, no oil leak!' CAA.... Contaminated air smell after engine start, during take-off and in climb. Cabin crew affected by fumes. Investigation found the cause seems to have been de-icing fluid contaminating the APU. A contaminated air smell was briefly evident after engine start and during take-off/climb. Oxygen was not used as the instances were brief and the smell quickly cleared. No smells were noticed during the remainder of the flight. Four members of the cabin crew reportedly felt unusually drowsy and sleepy. All club class passengers were asleep and the reporter comments that a carbon monoxide or contaminated air detection system would have enabled any possible link to be more clearly established. Aircraft inspection was carried out iaw Temporary revision D-5D-51 and a Conditional inspection was carried out iaw flowchart and work package 1. The engines were found satisfactory but after the APU bay was opened a noticeable amount of oil was evident in the cowling, which the reporter assumes was the cause of the oil smell. APU rendered inoperative and ADD raised for investigation. APU oil leak was suspected as the cause. Engineering investigation led to cleaning of the APU. The APU was then inspected while running. Nil evidence of oil leaks. APU bleed duct removed and inspected with nil evidence of oil contamination. Packs purged-no smells were evident during pack operation. However, the APU bay was found contaminated with de-icing fluid. Bay cleaned - APU run again with no smell in aircraft. This event appears to have been caused by contamination with de-icing fluid. No recurrence during the month after this intervention; active monitoring being done. See also 200305917 and 200508808. CAA Closure: The hazard is adequately controlled by the actions stated above.
4-Feb-2006	B757		Fume event - G-BYAT
4-Feb-2006	B757		Fume event - G-BYAT
5-Feb-2006	B757		Fume event - G-BYAT

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5-Feb-2006	B757		Fume event - G-BYAT
7-Feb-2006	B777	200600913	BA 184 / EWR-LHR / DIVERTED INTO BOSTON / P1:DAVSS P2:MONNS / G-VIIW / BA Ref:269548 Dull thump was heard/felt with a brief slight vibration followed by acrid fumes in the flight deck. Crew donned oxygen, declared a MAYDAY and carried out the checklist. The fumes quickly dissipated. Diversion to BOS was initiated where the aircraft made an uneventful overweight landing. Fire Service attended with heat sensing equipment. The aircraft then taxied to the terminal to disembark the passengers. AAIB Initial Notification: Acrid smoke on flight deck due Air Cycle Machine (ACM) failure. Flight crew donned oxygen masks. MAYDAY declared. Diversion to Boston. Overweight landing.
8-Feb-2006	Bae 146	200601042	G-JEBB / Fumes inside the aircraft. Captain and cabin attendant felt unwell. In the cruise at FL160 a smell of oil was apparent on the flight deck, although nothing was visible. During the approach, the Captain noticed that his throat, nose and lips had dried up. He subsequently reported feeling drowsy and found that he had problems with his memory. He later attended hospital for tests but nothing conclusive was found. On the following day, the Captain still felt very tired and had a dry throat. He also discovered that a cabin attendant on the same flight had noticed a smell on landing and had felt dizzy thereafter. Following an engineering inspection, the air conditioning packs were changed after oil had reportedly been found. However, a similar incident involving the same aircraft was reported two days later (occurrence number 200601036 refers). See also 200601027 (different aircraft - DHC8) same departure airport on the previous day identified as local environmental issue?
9-Feb-2006	B757		Fume event - G-BYAO
9-Feb-2006	Q400	200601027	G-JECH / Strong fumes inside aircraft. During taxi out strong fumes were apparent on the flight deck and in the cabin, necessitating a return to the stand. The smell was described as being similar to tarmac/bitumen and the source was subsequently identified as local environmental (a ship in the nearby dock was offloading petrochemical products). The flight recommenced and departure proceeded without further incident. However, approximately 15 minutes before landing the cabin crew reported similar fumes in the cabin. The engine bleeds were deselected in turn and the cabin crew reported improved air quality but the smell still lingered. After disembarkation the cabin crew reported feeling the after effects of the fumes (nausea and headaches). Ground runs were carried out but it was not possible to reproduce the fumes.
10-Feb-2006	Bae 146	200601036	G-JEBB / Fumes on flight deck and in forward cabin. The Captain and two cabin attendants were aware of fumes during the cruise. The Captain reported being unable to concentrate and one of the cabin attendants reported slightly blurred vision. After landing and engine shutdown, all crew members felt normal. Investigation progressed under 200601042 (same aircraft two days earlier).
12-Feb-2006	A320	200601074	G-EUUI / LHR. Oily smell inside aircraft when APU bleed air was used to supply air conditioning. No fault found. The smell dissipated when the bleed was switched off. APU bleed air was left off until engine start. No fumes were detected after engine start, although the cabin crew reported that the smell returned briefly after take off. No further report during flight or on arrival and no fault found.

Appendix 1: Incidents on the UK contaminated air database as of 1 August 2006

12-Feb-2006	B747	200601098	TF-AME / LGW. AAIB Initial Notification: PAN declared due to electrical burning smell and smoke on the flight deck. Aircraft landed safely. No fault found.
13-Feb-2006	BAe 146	200601096	G-JEBB / LGW. Fumes on the flight deck and cabin. Following a normal unpressurised take off when the packs were reinstated with engine bleed, there was an immediate smell of fumes. This later subsided until the approach when the smell was apparent again. The symptoms recurred on the return sector. After the second flight both flight crew were in no doubt that the fumes were present after the packs were brought on line using engine bleed. In addition an experienced member of the cabin crew became aware of an unusual smell at the rear of the aircraft after take off, which seemed to disappear after a few minutes. Investigation being progressed under 200601042. See also 200601036.
16-Feb-2006	A319	200601255	G-EZEV / BRS. Smoke and strong burning smell during passenger boarding. Pack 2 used during initial passenger boarding but when Pack 1 switched on, smoke and a strong burning smell noted in the cabin. APU bleed and both packs switched off and precautionary passenger disembarkation carried out. Engineering investigation suggested cause was oil from APU. Fault rectified and passengers re-boarded.
16-Feb-2006	BAe 146	200601216	G-JEBG / AAIB Initial Notification: F/O incapacitated due to smoke/fumes. A/c returned to stand and F/O taken to hospital. No other crew affected and nothing seen. Subject to AAIB AARF investigation. See also 200600197, 200600814, 200601036 and 200601042.
16-Feb-2006	B757	200601226	G-BMRD / CGN-LEJ / Fumes on flight deck. On boarding the aircraft it was noted that there were a number of tech log entries regarding fumes on the flight deck, with an engineering recommendation to "start with recirc fan off if required". As soon as the RH engine was started fumes were smelt so the recirculation fan was switched 'off'. The fumes persisted so RH engine bleed and isolation switches were selected 'off'. The LH engine was then started, the APU was shutdown and RH bleed was selected 'on'. The system was operated on the ground with the LH pack only and the fumes cleared. On the subsequent landing the flight deck filled with acrid fumes. Both packs, recirc fan and bleeds all selected 'off'. The crew were left feeling light headed, with stinging eyes and irritation of the facial skin and throat. The symptoms mostly cleared when exposed to fresh air. However, as a precaution, the crew attended hospital and were assessed as fit to fly.
17-Feb-2006	SF 2000	200601339	Aberdeen. Pilot reported burning smell on board parked aircraft and requested AFS attendance. Emergency actions initiated by ATC, later downgraded by AFS to local standby then cancelled.
21-Feb-2006	B737		EI-ZZZ / Indesi. PAN declared due to fumes on the flight deck. Crew donned oxygen masks. Priority approach given later downgraded by AFS to local standby then cancelled.
21-Feb-2006	BAe 146	200601356	G-JEBA / IOM. Oil smell during the cruise. During the cruise, flight crew noted an oil smell, requiring both to use oxygen for approximately five minutes. The smell then cleared. The reporter adds that after landing on the preceding flight, cabin crew noticed a strong smell of oil in the forward galley, the rear galley and in the area of seat rows 1 and 2. APU exhaust gasket p/n HC498H0004-202 found damaged and replaced. Modification to improve APU sealing raised under SB 49-067-36230A. Investigation progressed under 200600814.
22-Feb-2006	BAe 146		Fumes event

22-Feb-2006	Bae 146	200601384	G-JEBD / AAIB Initial Notification: Oil fumes in cabin. All three cabin attendants reported adverse symptoms. Subject to AAIB AARF investigation. On arrival it was reported that a cabin attendant felt "ill and dizzy". She had spilled coffee on a passenger and had thereafter been unable to operate the flight. Oxygen was administered and the medical crew at the fire station were called. All cabin attendants were consulted and one mentioned noticing a smell of oil after take off and subsequently suffered tingling in the hands and fingers. Another reported having a headache which eased when oxygen was administered. All crew members attended hospital for a medical check and blood tests. See also 200409537 (same aircraft).
23-Feb-2006	B737	200601777	G-GFFF / ASR / MOR / EDI-EDI / BA 2940 / B737-500 / Very strong smell of fumes throughout aircraft after engine start. Aircraft was carrying ADD "APU not to be used due suspected fuel leak - After start strong smell of fumes" After engine start in EDI packs were placed on and strong smell of fumes smelt throughout aircraft. Aircraft returned to stand. Engineers checked for problems. Passengers disembarked. Engine started again and there was a strong smell of fumes through out the aircraft. Engineers carried out work on aircraft overnight. Next day APU defect cleared due 'no fault found'. APU used for air conditioning resulting in smell of fumes. Aircraft flown unpressurised back to LGW. Investigation led to the fuel heater and associated NRV being replaced. There have been no further reported occurrences since the operator has replaced the fuel heater assembly. CAA Closure: The hazard is acceptable provided the frequency remains low
24-Feb-2006	B757	200601517	G-BPEC / Transient fumes on take off LHR. Oil levels later found to be at '18' & '19' instead of operator's limit of '17' & '18'.
2-Mar-2006	Q400	200601635	G-JEDN. BHX. Burning smell on flight deck and in galley. This crew's first sector, which was the subject aircraft's third flight of the day, was uneventful apart from difficulty in controlling flight deck temperature in the cruise, due to the air pack's auto mode being inoperative. During the latter part of the turnround, on returning to the flight deck, a distinct smell of fumes was apparent, which cleared when APU bleed air was turned off. During pushback, the 'Flt Comp Duct Hot' and 'Cabin Compt Duct Hot' cautions illuminated. The first officer used the emergency checklist to clear the captions but the smell returned and the cabin crew reported a similar smell to the rear of the cabin. The aircraft taxied to a remote stand and was shutdown awaiting engineering assistance. No fault found. Investigation being progressed under 200510566.

4-Mar-2006	B757	200601949?? 200601984??	BA 558 / G-CPEO / ASR / MOR / LHR-FCO / BA558 - Toxic fumes in the flightdeck. During descent with engines at ideal during short use of engine anti ice, P1 asked P2 if he could smell contaminated air, P2 stated could only smell a 'vanilla' type smell. Engine anti ice selected off and contaminated air / vanilla smell seemed to clear so no further action taken as type / concentration of perceived transient contamination could not be confirmed and both crews felt OK and behaved normally. P1 next day felt slightly nauseous but fit to fly but by late evening nauseous feeling was now also a slightly sick feeling which lasted several days but P1 could still run / cycle and function normally. On 06 March 2006 P1 went for blood test to investigate any chemical exposure evidence. P1 also had typical skin sensitization blister on the nose thought to be linked to skin sensitiser ‘PAN’ present in synthetic jet engine oils at 1%. Blood test confirmed significant exposure to pyrolised engine oil ingredients as blood showed raised levels of Benzene, Toluene, Xylenes, Dichlorobenzene and various Aliphatic compounds as well as the organophosphate TCP. Blood test also showed genes chemically blocked as well as significant increase in cell degradation. Blood test results also found significant amounts of Nickel in the blood. Turbine blades, discs and other critical parts of jet engines contain alot of nickel superalloys. It is concluded that the smells noticed when the engine anti ice was temporarily selected on was an increase in what was most likely a continous exposure which the crew were unable to detect by smell. As crews have no requirement to have a sense of smell and everyones ability to smell will differ and many chemicals / compounds have no smell, contaminated air detection systems or filtration devices should be fitted as a matter of priority as outline by the industry group ASHRAE SPC-161 and others.
4-Mar-2006	A319		G-EUPT / BCN-LHR / BA477 / ASR / During take off a slight oily engine smell was apparent on flight deck which dissipated during climb. Cabin crew entered flight deck but nothing abnormal at that stage. During final descent into LHR at about 15000 feet both pilots noticed smell again. After shutdown cabin crew confirmed smell. Oxygen not used initially due to dissipation and severity (mild).
4-Mar-2006	B757	200602526 ???	BA548 / G-CPET event of 10 March refers to this event. No extra data available
6-Mar-2006	A320	200601787	EI-ZZ / PAN declared due to smoke on flight deck. Aircraft instructed to squawk 7700 and descended to FL210. Diverted to Manchester.
7-Mar-2006	BAe 146	200601770	G-JEBA. Suspected cabin air contamination. During the cruise, two cabin attendants in the forward galley reported feeling unwell (light headed / headache). Oxygen was administered and the symptoms improved slightly but on resuming normal operations the symptoms returned and were still present after landing. The flight crew and rear cabin attendant felt no symptoms but smelt fumes on APU air. Investigation being progressed under 200600814.
8-Mar-2006	BAe 146	200601907	G-JEBA. Fumes in cabin. Fumes smelt by cabin crew (who reported symptoms of sore throats) in the vicinity of rows 8 and 12. Fumes cleared when pack 2 was selected 'off'. See also 200601356. Investigation being progressed under 200600814.

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8-Mar-2006	A319	200601967	G-EUPY / MOR. Smoke and haze in flight deck and cabin. Approximately five minutes after APU start while raining, the flight deck and cabin filled with a light haze and burning smell. Passengers were disembarked and fire services attended, who confirmed no fire to be present. Suspected cause was water ingested into the APU intake. Boarding resumed normally after engineering checks.
8-Mar-2006	A321		ASR / G-EUXD / BA736. Passing 15000ft on desent, and up to approx the same level in the cllimb there was a strong oily smell, similar to 'sweaty socks'. Both crew noticed the smell, and after the smell dissipated Captain commented that he had a slightly sore throat, and a light irritation around the eyes. The copilot agreed he had experienced similar symptoms.
9-Mar-2006	A320	200601879	ASR / MOR / G-EUUO / LHR-IST / BA680. Shortly after switching on the APU bleed air (during passenger boarding) an unusual smell was noticed on the flight deck and in the cabin. The cabin crew then reported a slight smoke haze coming from the cabin air vents. Passengers asked to disembark.Engineering stated the cause was 'heavy rain washing dirt into the APU inlet'.
10-Mar-2006	B757	200601949	BA548 / G-CPET / LHR-FCO / ASR - Fumes on flight deck after engine start. Partial flight crew incapacitation. After starting both engines (first flight of the day) F/O smelt fumes and discussed with Captain. After about 2 minutes F/O started to feel light headed and uphoric and unwell. Captain aslo felt light headed. Waited on taxyway to see if the situation changed but both flight crew felt abnormal. First Officer considered himself poartially incapacitated. Cabin crew appeared unaffected. Aircraft towed to a stand and F/O went on oxygen for the 10 minutes this took and felt better. Aircraft withdrawn from service. Engineering advised previous event on this aircraft on 4 March 2006. Tech log reference: 01/2675/01 See also 200602526. BAHS contacted and advised flight crew to stand down. Engineering advised of a previous event with this aircraft six days earlier for "occasional brief smell on the flight deck. No smell in cabin". No defects found, aircraft returned to service.
14-Mar-2006	A321	200602004	MOR / TFS / -200 / Smoke and fumes evident with APU bleed on. APU rendered inoperative. The flight crew reported white smoke emanating from vents around the APU and a pungent smell from the air conditioning packs when APU bleed air was on. The APU was not used for the return sector. On investigation, when the APU was started in order to conduct a leak check, a leak from the lower turbine oil pipe ignited causing a small fire. The APU was immediately shutdown and further inspection showed that the lower turbine area was blackened by soot/oil. APU rendered inoperative pending rectification.
16-Mar-2006	BAe 146	200602229	G-JEBF / En route. Oil' smell in cruise traced to soup being prepared in forward galley. In the cruise both flight crew noticed an unusual smell that was initially thought to be oil based and a similar smell to that of an oil-fired central heating boiler. After a few more minutes it was then thought that the odour also smelled like soup and after investigation it was discovered that the 'oily' smell was soup being prepared in the forward galley. The reporter is of the opinion that both these smells are similar and questions whether this could be related to the recent air quality incidents.
17-Mar-2006	Q400	200602374	G-JEDL / Cabin crew felt "dizzy" and flight crew found difficult to concentrate during flight. During the cruise, both cabin crew reported feeling queasy and dizzy with headaches and stomach pains. Neither the Captain nor First Officer felt unwell at this time but as a precaution, the flight deck door was set in the 'keylock' position. A bleed air test of both nrs1 and 2 bleed air systems was carried out, leaving each system on for approximately five minutes

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19-Mar-2006	BAe 146	200602173	HB-IXS / ZRH / AAIB Initial Notification: Smoke on flight deck just prior to landing. Uneventful landing. Aircraft stopped in R/W exit area and emergency declared due smoke on flight deck and in cabin. Smoke emitted from the RH side of flight deck.
19-Mar-2006	Q400		Q400 Event, with Cabin Crew, No2 (Bio -accumulation?) Feeling unwell due Fumes. Captain tells No 2 he cant smell anything, its just her imagination!!! No 2 also had another Event either previous day or day before.
20-Mar-2006	BAe 146	200602204	G-JEAM. LGW. Fumes in the cabin. The cabin crew and some passengers remarked on 'chemical' fumes in flight and during taxi-in. The first officer also became aware of similar fumes. Two passengers were asked to remain behind to obtain further details iaw recent company NOTAC. Both passengers, three cabin attendants and the first officer suffered minor fume symptoms. The crew members attended hospital for tests and the passengers were invited to do likewise but declined.
20-Mar-2006	BAe 146		G-JEAM / BHD - LPL. Capt No effects. F/O some effects / Nos 1 ,2 & 3 all had Metallic Taste in mouth. No1 nauseous next evening with Vomiting, No2, Blood Test Abnormalities CarboxyHaemaglobin. No3, Just Metallic Taste in Mouth on the day.
21-Mar-2006	BAe 146		Fume Event
22-Mar-2006	B757	200602516	G-BPEI. En Route. Electrical smoke smell in cabin and later in flight deck. Electrical smoke smell noted in the cabin in the area of Row 12, before the smell was then detected in the flight deck. Smoke fumes / fire electrical drill carried out with flight deck crew using oxygen. PAN declared. Emergency services requested for landing although the aircraft taxied to the stand for disembarkation.
24-Mar-2006	EMB145	200602293	AAIB Initial Notification: Popping noise heard through avionics, accompanied by distinct smell in cockpit. PAN declared.
26-Mar-2006	B777	200602370	Willo Hold .PAN declared due to smoke in cockpit.
4-Apr-2006	B757		BA556 / G-CPES / LHR-FCO / ASR / MOR - Strong fumes smelt on takeoff and initial climbout On packs on after start, fumes smelt, faintly on taxi out then very strongly on takeoff & initial climbout. CSD contacted and when shearrived on flight deck she confirmed a strong chemical smell. Oxygen donned by flight crew QRH memory drills actioned. After 5 minutes CSD returned to flight deck and stated smell had reduced by 50%. After 5 more mins Captain removed mask and CSD returned, agreed smell was gone and so co-pilot removed mask and flight continued normally.
12-Apr-2006	BAe 146	200603108	G-JEBB / -300 / MOR / BHD / Fumes in cabin. While on stand following flight, the SCCM reported that she and another crew member had headaches, "had a peculiar feeling, best described as 'moon walking'" and felt lethargic. The Captain suggested they take oxygen in an effort to clear their headaches but at this time a third crew member felt tingling in her hands. The SCCM also appeared very confused, using incorrect names for the Captain and nr3 cabin crew. Cabin crew were taken to hospital for examination and engineers sealed the aircraft. The First Officer recalled that he had noted a slight fume smell on pushback during the preceding flight. Engineering unable to find fault. Cabin air quality check carried out no contamination found. See also 200601042 same aircraft on 8.2.2006 and 200601036 on 10.2.2006.
12-Apr-2006	CB560XL		MOR / CS-DFR / EIDW-LEMG / After take off 'Bleed air duct" illuminated. 10 sec later "air duct overheat" and 30 sec later "emerg press", "ACD O'vheat" illuminated. Associated with this event: Very hot air in cabin, loud noise from rear and very light mist of smoke. Decision to come back and land in EIDW after having done all the check lists. Aircraft landed overweight at 19400 lbs.

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16-Apr-2006	B737	200603229	MOR / G-DOCN / NCL / 737-400 / LH pack tripped off with over temperature warning. Fumes / smell on flight deck. Before take off, the LH pack tripped off with an 'Over Temperature' master caution activating. QRH actioned during the climb resulting in the pack being reinstated, although a "hot pack smell" was noted in the flight deck and cabin which quickly dissipated. Flight crew donned oxygen masks for approximately 10 minutes as a precaution. The smell returned during approach, the pack was switched off and the smell cleared following landing.
25-Apr-2006	A340	200603394	MOR / New York / -300 / G-VAEL / Smoke/fumes in cabin. In the climb at 1500ft, the cabin crew reported hazy smoke and a strong smell of burning in the cabin. The symptoms appeared worse in the area of L/R2 and APU or engine bleed was considered as the probable cause. The cabin crew donned oxygen masks as a precaution and the smoke/fume removal checklist was actioned. After 30 minutes the fumes cleared and the flight continued to LHR. The reporter notes that the same a/c and crew had been involved in a similar incident two days earlier when the a/c had returned to EWR.
27-Apr-2006	B757		Fume event - G-BYAU
1-May-2006	B777		ASR / MOR / G-VIIX / BA188 / EWR-LHR / Strong smell on flight deck, smelt musty citrus clinical at 14000feet at 250Kts descending 13,000 feet. Smell disapted at 13,000 feet at 210 Kts. Smell again at power up at 5000 feet and smell again on shut down.
4-May-2006	B757	200603701	G-CPEP / LGW. Fumes/vapour contaminated flight deck after engine start - LH engine slow to spool up and accelerate. During LH engine start N2 maximum motoring was 9% slow to spool up. On completion of the after start panel scan, droplets of contaminate (oil/fuel suspected) were expelled from the P2 fresh air vent into his mouth. The P2 experienced a mild stinging sensation on the tongue and had to gargle with water and rinse his mouth out to reduce the offending taste. On the take-off roll, the LH engine was slow to accelerate and failed to achieve target EPR without manual intervention.
12-May-2006	B777	200603921	G-VIIV / GE90 / Fumes in cabin and on flight deck. Fumes cleared from cabin after recirculation fans switched off but remained on flight deck until equip cooling fan switched off.
15-May-2006	BAe 146	200603926	G-JEAJ / BHD / MOR / Suspect air contamination. The APU was started for electrical purposes prior to flight with controls set to minimum heating. APU air was selected 20 minutes later and almost instantly a hot burning oil smell was detected by both pilots and two forward cabin crew, although the cabin crew at the rear were not affected. All four forward crew complained of similar symptoms, i.e. dry throat, itchy eyes, nausea, and dry nasal cavity. Affected crew were transferred to hospital for examination/tests.
16-May-2006	B757	200603966	G-BMRF / BRU. Strong smell of oil on flight deck. Both flight crew reported eye, nose & throat irritation.
16-May-2006	B757	200603995	G-BIKS / Oil fumes on flight deck. The P1 states that having operated 4 sectors on this aircraft there is still oil vapour/fumes on the flight deck during APU start up, engine start and the initial climb to FL200. The fumes then dissipate and return in the final stages of the approach causing the handling pilot to suffer dry/stinging eyes. Aircraft grounded at Brussels and declared AOG pending investigation. See also 200509210.
16-Jun-2006	B757		G-BIKK / BRU-FRA-PRG. Smells on both flights. See next sector
16-Jun-2006	B757		G-BIKK / PRG-FRA. Fumes worse than previous two sectors (see above). P2 smells and comments on stroung fumes. P1 strong smells and metallic taste in his mouth. In hotel both crew had the giggles and not feeling well. Crew went to hospital who only did basic tests.

25-Jun-2006	B757		Resume sent in: 'On Sunday 25 June I flew to Alicante. After departure we had the toilet smoke sensor alarm sound, together with a strong smell of burning in the flight deck. The smell then changed to a sweet, sickening smell. All crew on board were aware of this and reported it to the Captain and myself. After approx 30 minutes I decided to go onto oxygen as I was suffering from headache and dry throat. We elected to continue the flight as the smell appeared to diminish. At top of descent the smell came back again. On arrival the company engineer found nothing unusual.' SEE 27 JUNE SAME AIRCRAFT
25-Jun-2006	A320		CDG / Oil fumes on the ground / cabin crew with rashes on arms and legs
26-Jun-2006	B757		G-BPEJ / Taxi out / ASR / MOR ? / Fumes before engine start and afterwards. P2 not feeling well on taxi out and went onto oxygen. P1 Not too good either. Cognitive problems trying to taxi aircraft back on stand and operating aircraft systems like lights. Problems doing the PA. Cabin crew reported feeling ill effects.
27-Jun-2006	B757		I was flying the same aircraft to Crete. After engine start and take off we got the same smells in the flight deck. However no serious symptoms were noticed. However at top of descent the smell returned, much stronger and also with pronounced effects. The passengers questioned the cabin crew as to what the smell was, although none of the passengers reported any symptoms. Once the passengers had disembarked the aircraft all crew on board started to feel significantly worse. Some experienced blurred vision, all had headache, dry throat, unusual taste in the mouth and a feeling which can only be described as detached from what was going on around us. Obviously we were all concerned. On speaking to company we went to the doctor at the airport, then to the local hospital were blood samples were taken but nothing unusual found. Anther crew positioned to Crete to operate home, while we sat down the back of the aircraft. The flight home was operated with the air conditioning system configured so that the left system was isolated. Flight back to London uneventful. We are all concerned about this matter regarding the medium - long term effects of this contamination.'
8-Jul-2006	B757		G-BPEJ / GLA-LHR / BA1483 / Tech Log 'Transient Smell' / Cabin crew report smell coming out of aircraft vents.
9-Jul-2006	B757		Airborne return. Details pending

Appendix 2:

BAe 146 Service Bulletins Service Information Leaflets and data confirming CAQ problem

Appendix 2: BAe 146 Service Bulletins, Service Information Leaflets and data confirming Cabin Air Quality problem

Date	In Service Evaluation	Type Of Report	Reference	Who	Title	Reason / Notes	Compliance	Cross Reference
04/09/1985	05-06-87 rev 3	Service Bulletin	SB 21-24- 00543A	BAe	Air conditioning- Improve sealing between hydraulic bay & passenger compartment.	**Reason:** Fumes from hydraulic bay have entered the passenger compartment when aircraft unpressurized, after hydraulic system failure.	Mandatory by UK CAA by by 31May, 1986: CAA approval # DAI/1011/55	
28/02/1987		Service Bulletin	SB 21-054	BAe	Air conditioning: Inspect emerg ram air-poss hydraulic fluid contamination of flexible hoses.		Recommended: CAA approval # DAI/1011/55	
09/05/1990		Service Bulletin	SB 21-054	BAe	Air conditioning- Introduce replacement ram air flexible ducts manufactured from hyd resistant material.		Recommended: CAA approval # DAI/1011/55	
12/01/1993	31/05/1993	Service Bulletin	SB 21-70- 01316A	BAe	Air conditioning- Introduce improvements to bleed air & air conditioning systems to eliminate cabin odours.	**Reason**: Service experience has highlighted requirement for improved quality conditioned cabin and flight deck air. **Description**: Introduces a number of modifications which combine to form complete filtration system for conditioned air to cabin & flight deck areas. Partial embodiment acceptable.	Information: CAA approval # DAI/1011/55	BAe SB 71-56-50217A

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01/02/1993		Service Bulletin	SB 21-071- 01316A	BAe	Air conditioning- Introduce improvements to bleed air & air conditioning systems to eliminate cabin odours.	In service evaluation.	Information: CAA approval # DAI/1011/55	
15/12/1993	20/10/1995	Service Bulletin	SB 21-72-01316 A&C	BAe	Air conditioning- Introduce improvements to the bleed air and air conditioning systems to improve conditioned air quality.	**Reason**: Service experience has highlighted advantages in improving the quality of cabin and flight deck air. **Description**: Install odour & particle filtration units to cabin & flight deck air supply ducting, remove engine catalytic converters…	Optional: CAA approval # DAI/1011/55	NGL mod # 573TC
		Service Bulletin	SB 21-073: Cancelled	BAe				
		Service Bulletin	SB 21-074: Cancelled	BAe				

22/12/1993	16/03/1994	Service Bulletin	SB 21-77-01316C	BAe	Air conditioning- Removal of coalescers from air filtration system and associated change to environmental conditioning system packs.	**Reason**: In service experience & testing has shown that oil coalescers are not effective in extracting engine / APU oil in aerosol form from air conditioning system. Removal of coalescers will in consequence also reduce the required aircraft maintenance. **Description**: Recommended reinstallation of APU catalytic converter to improvethe service life of the downstream remaining odour & particulate filter elements.	Optional: CAA approval # DAI/1011/55	
31/08/1993		Service Bulletin	SB 21-078	BAe	Air conditioning- Distribution- Inspect duct joint in flight deck air conditioning supply line.			
31/08/1993		Service Bulletin		BAe				
18/10/1993		Service Bulletin	SB 21-079- 01316F	BAe	Air conditioning- Distribution- Reinstallation of passenger cabin & flight deck filter elements.		Optional: CAA approval # DAI/1011/55	

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15/07/1998	16/07/1998	Service Bulletin	SB 21-119-40424E	BAe	Air Conditioning- Air distribution- introduce additional conditioned air into forward vestibule	**Reason**: Enhance distribution of conditioned air within the forward vestibule	Optional: CAA approval # DAI/1011/55	
07/04/2000		Service Bulletin	SB 21-127- 70549B, E	BAe	Air conditioning- Cabin & flight deck filter - Introduce interchangeable filter elements with increased change intervals for cabin & flight deck filters.		Information: CAA approval # DAI/1011/55	
		Service Bulletin	SB 21-128 to 21-148 2000-2001- various dates	BAe	Believed to be internal airflow changes, toilets, galley….			
		Service Bulletin	SB 21-149	BAe				

20/03/2001	29-01-02-rev 1 24-10-02-rev 2	Inspection Service Bulletin	ISB 21-150	BAe	Air conditioning-Inspect engine oil seals, APU & ECS jet pump & air conditioning pack for signs of oil contamination.	**Reason**: Incidents have been reported involving impaired performance of the flight crew... In the past, oil leaks and cabin / flight deck odours and fumes may have come to regarded as a nuisance rather than a potential flight safety issue. whilst investigations are being carried out, oil leaks and cabin / flight deck odours must be regarded as a potential threat to flight safety, they should not be dismissed as a mere nuisance and should be addressed as soon as possible.	**Mandatory** by UK CAA: CAA approval # DAI/1011/55: Refer CAA 002-03-2001 / CASA AD BAe 146/86	

31/10/2002		Inspection Service Bulletin	ISB 21-156	BAe	Air conditioning- To inspect air conditioning sound attenuating ducts for signs of oil contamination.	**Reason**: Incidents have been reported involving impaired performance of the flight crew... In the past, oil leaks and cabin / flight deck odours and fumes may have come to regarded as a nuisance rather than a potential flight safety issue... oil leaks and cabin / flight deck odours must be regarded as a potential threat to flight safety, they should not be dismissed as a mere nuisance and should be addressed as soon as possible. This ISB is intended to supplement the ISB.21 150... It has been shown ...that sound attenuating material within these ducts has acted as an absorbent for oil contamination on some aircraft.	**Mandatory** by UK CAA: CAA approval # DAI/1011/55: Refer CAA AD #003-10-2002 / CASA AD BAe 146/102	

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24/04/1987	26-10-87 rev 4	Service Bulletin	SB 36-13-35078 A&B	BAe	Pneumatics- APU air supply- Introduce catalytic converter in APU bleed air system.	**Reason**:APU oil leakage has caused contamination of bleed air, resulting in odour problems in passenger compartment, and ECS ... contamination. **Description**: ...introduce catalytic converter into APU Bleed air duct systems to reduce odour, and to break down any airborne oil products	Optional: CAA approval # DAI/1011/55	
23/09/1987		Service Bulletin	SB 36-14-35044B	BAe	Pneumatics- APU air supply- Introduce installation improvements to bleed air ducting.	**Reason**:Instances have occurred where the APU bleed air duct couplings have become misaligned resulting in air leaks	Optional: CAA approval # DAI/1011/55	
01/11/1993	10/11/1993	Service Bulletin	SB 36-28-36136B	BAe	Pneumatics- Reintroduction of catalytic converter to APU.	**Reason**:As part of a group of modifications introduced to eliminate cabin odours, the catalytic converter was removed from the APU air supply ducting. ...fitment of the APU catalytic converter significantly increases the service life of the downstream odour filtration system elements.	Optional: CAA approval # DAI/1011/55	

24/10/1984		Service Bulletin	SB 49-5-35040G	BAe	APU- Power plant - Introduce an improved compressor inlet duct seal (Garrett change 13).	**Reason**: Inadequate sealing between APU accessory drive gearbox oil sump & compressor inlet duct, and between top & bottom halves of inlet duct, allows fumes to be sucked from the bay area through the APU and into passenger cabin. **Description**: Improved silicone rubber seal configuration... This SB is for information only. Retrospective embodiment is not intended because in service experience has shown that this modification is not a complete answer to the problem. Garrett Change 19 (BAe SB 49-8-35040S) to be issued shortly.	Information: CAA approval # DAI/1011/55	BAe SB 49-8-35040S
01/10/1984	18-05-93 Rev 2	Service Bulletin	SB 49-6		APU- To introduce piping to route the gearbox vent outlet overboard.	**Reason**: Investigations into the problem of odours in the passenger cabin indicate that oil spillage from the gearbox vent is a potential source. At present the gearbox vents into the APU bay. An improved arrangement which vents overboard is required.		
		Service Bulletin	SB 49-8-35040S	BAe				

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14/01/1985		Service Bulletin	SB 49-10- 35040P	BAe	APU- Introduce improved sealing of APU plenum joints (Garrett SB GTCP-36-49-5563).	**Reason**: Prevent contamination of the APU bleed air.	Optional: CAA approval # DAI/1011/55	Garrett SB GTCP-36-49-5563
06/06/1985	06-07-85 18-05-93	Service Bulletin	SB 49-13-35040R	BAe	APU- Engine- Introduce change # 18 to APU (Garrett SB 36-49-5562)	**Reason**: As a result of investigations into bleed air contamination, an oil leakage source has been identified at the attachment of the compressor seal housing to the planetary housing. **Description**: New attachment bolts, improved spot facing & sealing, and higher temperature rated compressor shaft 'O' ring seal to prevent the possibility of oil leakage.		Garrett SB 36-49-5562
25/09/1985		Service Bulletin	SB 49-16-35055A	BAe	APU- Engine- introduce change #27 to APU unit 3800086-1 or – 4 (Garrett SB GTCP 36-49-5592)	**Reason**: Reduce the migration of oil from Sunstrand Generator / adapter assembly to Garrett APU.	Recommended: (next convenient overhaul of the generator/adaptor assembly) CAA approval # DAI/1011/55	Garrett SB GTCP 36-49-5592
16/12/1988	11-08-97 rev 8	Service Bulletin	SB 49-25-36019A	BAe	APU- Introduce Allied Signal / Garrett APU model GTCP36-150 (M)	**Reason**: To achieve common standard APU.	Optional: CAA approval # DAI/1011/55	

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14/01/1991	21/08/1991	Service Bulletin	SB 49-28-36098B	BAe	APU- Air intake- to provide improved sealing of the air intake duct within the APU bay.	**Reason**: Sealant no longer manufactured -some airlines have reported contaminated air being drawn from APU bay in to the air conditioning system following APU cooling fan oil leak. **Description**: Introduction of spacer to APU air intake / inserted b/w top flange of flexible duct & inner face of firebox recess.	Recommended: (at next routine APU removal) CAA approval # DAI/1011/55	
		Service Bulletin	SB 49-26	BAe				
14/01/1991	21/08/1991	Service Bulletin	SB 49-28-36098B	BAe	APU- Air intake- to provide improved sealing of the air intake duct within the APU bay.	**Reason**: Sealant no longer - some airlines have reported contaminated air being drawn from APU bay in to the air conditioning system following APU cooling fan oil leak. **Description**: Introduction of spacer to APU air intake, inserted b/w top flange of flexible duct & inner face of firebox recess.	Recommended: (at next routine APU removal) CAA approval # DAI/1011/55	

12/05/1992	02/05/1996	Service Bulletin	SB 49-30- 36115B	BAe	APU- Exhaust- provide improved sealing at joint b/w APU exhaust flange & shroud.	**Reason**: When APU exhaust flange bolts tightened, exhaust flange is dimpled into large clearance holes in shroud which causes distortion b/w bolts. This can result in leakage of APU exhaust into bay which may lead to Smells in passenger cabin. **Description**: Large special washers (as used on the shroud side of the joint) & no longer bolts at APU exhaust flange.	Information: CAA approval # DAI/1011/55	
30/04/1992		Service Bulletin	SB 49-31-36115A	BAe	APU- To provide improved sealing at joint b/w APU intake flange & flexible duct.	**Reason:** Possibility of ingestion of APU bay contamination with the existing design of the APU inlet plenum ballows. This can result In fumes entering the passenger compartment. **Description**: Improved flexible duct introduced to APU inlet flange / 2 locating bolts replaced with clamps to securely hold the faces of the inlet to the APU. Lower surface of inlet duct provided with improved seal to enable the duct to effectively seal against distorted APU flange.	Recommended: (at next routine APU removal) CAA approval # DAI/1011/55	

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16/03/1992	02/05/1996	Service Bulletin	SB 49-32-36127A	BAe	APU- Introduce APU bleed air connection seal part #BA7154 in place of existing seal part # BA6230.	**Reason**: The APU bleed air duct connector used on the 150 APU has 5 degree offset. If connector not installed in correct radial orientation, premature failure may occur. **Description**: Modification introduces a new bellows type connector which is not offset but sufficiently flexible to cope with alignment problems.	Recommended: CAA approval # DAI/1011/55	
01/06/1993		Service Bulletin	SB 49-35- 36115E		APU- APU ventilation bay ventilation improvements		Optional: CAA approval # DAI/1011/55	

06/07/1993	26-10-94 rev 2 30-04-03 rev 4 27-07-04 rev 5	Service Bulletin	SB 49-36-36019E	BAe	APU- Introduction of improved APU inlet flexible duct part # DXA07175.	**Reason**: Existing APU inlet rubber flexible duct is susceptible to damage by oil contamination. **Description**: Rectangular, metallic bellows duct is Introduced as a direct replacement for rubber bellows duct. Rev 4 **-** Contamination of cabin air due ingestion of oil from the APU bay is found to occur on the affected aircraft. This modification provides an improved seal at the aircraft – APU interface to prevent this. introduction of a rectangular metallic bellows duct incorporating an improved seal and clamp arrangement as a direct replacement for the rubber bellows duct. Rev 5 **-** introduces replacement of the bellows attachment hardware.	Optional: CAA approval # DAI/1011/55 Rev 4 & 5 made mandatory by CAA	See CAA AD 007-04-2003 (2003) CASA AD 146/105(2003) & 146/105 amdt1(2005) **MANDATORY**

11/10/1993	12 Jan, 1994	Service Bulletin	SB 49-38-36153A	BAe	APU- Introduce Allied Signal GTCP-150(M) APU Part # 3800216-2- complete with oil ejector system.	**Reason**: ...contamination of bleed air supply to cabin air-conditioning system experienced in service.Cabin odours have been attributed to oil leakage in APU. **Description:** Modification introduces new standard of APU with improved compressor inlet oil sealing and Integrated oil ejector system.This will reduce the possibility of internal oil leakage contaminating the bleed air supply and any oil from a seal failure will be ejected directly into the exhaust system.		
02/11/1994	22-10-98 rev 3	Service Bulletin	SB 49-39-30373A&E	BAe	APU- Introduce Sunstrand APU T-62T-46C-3 (for all series146/RJ previously equipped with AS/Garrett100(M) or 150(M) APU.	**Reason**: Introduce Sunstrand APU T-62T-46C3. **Description**: Various modifications incl. Improved exhaust duct support struts & mountings.		

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21/09/1994	02/02/1995	Service Bulletin	SB 49-044	BAe / AIA	APU– Exhaust-Inspect APU lower exhaust duct flange for possible cracking.	**Reason**: Endurance testing of the exhaust duct… has identified cracks in the flange… Cracking of this flange could lead to hot exhaust gases escaping into the rear air conditioning bay.	Recommended: CAA approval # DAI/1011/55	AIA - Avro International Aerospace
21/04/1995		Service Bulletin	SB 49-047 –36162A	BAe	APU- Introduce AS GT-CP-36 –100(M) APU part# 3800086-1 or 38000-86-4 (ejector system).		Optional: CAA approval # DAI/1011/55	
08/03/1995		Service Bulletin	SB 49-048- 36166 C&E	BAe	APU- Improved exhaust duct for use with Sunstrand APU T-62T-46C-3.	**Reason**: Lower exhaust duct susceptible to cracking.	Recommended: CAA approval # DAI/1011/55	
27/08/1996		Service Bulletin	SB 49-50-40372C	BAe	APU- Introduce mechanical changes to retrofit AS/Garrett GTCP36-150(M) APU on aircraft with Sunstrand APU T-62T-46C-3.	**Reason**: Customer requirement to replace Sunstrand APU T-62T-46C-3 with Allied Signal / Garrett GTCP36-150(M). **Description**: Introduces AS/Garrett APU model GTCP36-150(M) with dedicated exhaust, oil cooler system & necessary mechanical changes.	Optional: CAA approval # DAI/1011/55	

21/08/1997		Service Bulletin	SB 49-54-36190A	BAe	APU- Relocate Sunstrand APU gearbox vent pipe fuel drain, pipe & plenum drain pipe to reduce APU bay contamination & possible ingestion into APU / bleed air system.	**Reason**: Discharge of gearbox vent air through drain System may lead to contamination of APU bay when vent air contains oil mist. Bay contamination may result in reliability if electrical connectors become coated in oil… To eliminate this contamination the APU gearbox vent pipe and fuel drain pipe are relocated to discharge directly overboard. To eliminate the occurrence of oil mist entering the APU inlet via inlet plenum drain, this is relocated to APU bay door vent.	Optional: CAA approval # DAI/1011/55	
07/11/1997		Service Bulletin	SB 49-55-36189B	BAe	APU- Modify Sunstrand APU start / stop circuit to reduce occurrence of cabin smells.	**Reason**: In service reports have been received from customers about the occurrence of cabin smells associated with the operation of the APU. It is believed this phenomena is associated with the immediate de-powering of the electronic sequencing unit & de-priming valve when APU selected to stop.	Optional: CAA approval # DAI/1011/55	

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20/09/1999	31/03/2000	Service Bulletin	SB 49-56-36189B	BAe	APU- Modify Sunstrand APU start / stop circuit to reduce the occurrence of cabin smells.		Optional: CAA approval # DAI/1011/55	
28/08/1998		Service Bulletin	SB 49-57	BAe	APU- Inspect Sunstrand APU exhaust duct flange and felt metal interior of elbow section for cracking.	**Reason**: Cracking of the APU exhaust duct flange & felt metal interior around elbow section has occurred in Service - Damage to exhaust elbow seal carrier & incorrect seal positioning within seal carrier observed in service.	Recommended by CAA: CAA approval # DAI/1011/55	
25/08/1998		Service Bulletin	SB 49-060-36166F	BAe	APU- Introduce modified lower (elbow) exhaust duct to Sunstrand APS 1000 APU installation.	**Reason**: Cracking of the lower exhaust elbow's felt metal liner & flange inner radius reported in-service. **Description**: Improved std of lower exhaust elbow newly manuf. or repair std / tenons on lower support ring reprofiled to improve sliding action of exhaust unit in ring.	Information: CAA approval # DAI/1011/55	

28/08/1998		Service Bulletin	SB 49-061	BAe	APU- Inspect Sunstrand APU exhaust elbow duct flange for cracking.	**Reason**: Structural analysis of post mod HCM36166F exhaust elbow installation has shown that cracking of the flange may occur following 7000APU cycles. Damage to exhaust elbow seal carrier and incorrect seal positioning within seal carrier observed in service.	Recommended: by CAA: CAA approval # DAI/1011/55	
14/07/1999		Service Bulletin	SB 49-063-36203A	BAe	APU- Introduce revised APU combustor & modified exhaust flange drains to eliminate possible fouls Sunstrand APU-APS 1000.			
12/12/1986	05-08-91 rev 5	Service Bulletin	SB 71-034- 00723A	BAe	Power plant- Introduce catalytic converter in engine HP air bleed ducting.	**Reason**: Reports received of problems of odour in passenger cabin due to contamination of the engine bleed air when oil leakage occurs inside engine. (5 Aug 1991-rev 5 SB - modification HCM007232D introduces further improvements to catalytic converter).	Optional: CAA approval # DAI/1011/55	BAe SB 71-54-00723D
24/02/1987		Service Bulletin	SB 71-034	BAe	Power plant- Inspect catalytic converter in engine bleed air duct- sampling program.			

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09/06/1988	04/06/1993	Service Bulletin	SB 71-044- 00723B	BAe	Power plant- Modified catalytic converter assembly in HP air bleed duct.	**Reason**: In service experience with existing catalytic converter assemblies has shown that the elements within the converter can break free from their mounting. The elements may migrate into the HP bleed air duct.	Recommended next engine removal or convenient opportunity: CAA approval # DAI/1011/55	
13/02/1990		Service Bulletin	SB 71-054- 00723D	BAe	Power Plant- Introduce modified catalytic converter assembly in engine HP air bleed ducting.	**Reason**: In service experience with catalytic converter assemblies introduced by previous mods resulted in revised methods of retaining elements within converter housing. Further problems with modifications of catalytic assemblies showing breakdown of hermatite sealant and potential damage to catalytic elements and downstream equipment due to looseness of fit & inadequacy of upstream pinstops.	Recommended: CAA approval # DAI/1011/55	

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09/07/1990	10-10-97 rev 3	Service Bulletin	SB 71-056-50217A	BAe	Power Plant- Introduce engine air bleed duct without catalytic converter.	**Reason**: For customers who do not require catalytic converter elements installed in engine air bleed duct. **Description**: Removes engine bleed catalytic converter element from ducting and / or provides ducts without catalysts fitted.	Optional: CAA approval # DAI/1011/55	
28/07/2000	08/09/2000	Service Bulletin	SB 53-158- 30497A	BAe	Hydraulics- Improved sealing of hydraulics bay.		Recommended: CAA approval # DAI/1011/55	
		Service Bulletin	SB ALF 72-21	Allied Signal				
		Service Bulletin	SB ALF 72-22	Allied Signal				
		Service Bulletin	SB ALF 72-28	Allied Signal				
		Service Bulletin	SB ALF 72-31	Allied Signal				

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26/04/1984	01/06/2000	Service Bulletin	SB ALF 502 72-0076	Allied Signal / Honeywell	Engine- Introduction of improved no. 2 bearing assembly.	**Reason**: Introduce a No 2 bearing housing and air diffuser assembly with a no. 2 bearing housing that has increased radial clearance for better bearing oil damping, a leakage resistant oil inlet / outlet tube gasket on the air diffuser, and an improved bearing assembly gasket for better sealing between the retainer assembly and housing during pressure test.	Recommended at convenient access….	
09/12/1987	08-12-95 Rev 2	Service Bulletin	SB ALF/LF 72-0179	Allied Signal	Engine- Introduction of improved No.2 engine bearing.	This bulletin introduces an improved No. 2 bearing with a larger diameter anti-rotation pin to minimize pin shearing and subsequent bearing race rotation and wear.	Recommended at next access to affected parts	SB ALF 72-0076
		Service Bulletin	SB ALF 72-207	Allied Signal				
01/10/1990		Service Bulletin	SB ALF 72 -258	Allied Signal	# 9 bearing seals	# 9 Engine bearing /seal failure -alternate improved seal- # 9 bearing seal.		ALF 72-30-33
08/10/1991		Service Bulletin	SB ALF 72-279	Allied Signal	Engine- Introduction of 3rd turbine blade shroud….		Recommended when blades returned to service centre	SB ALF 72-270

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29/03/1995	March, 1995 rev 1	Service Bulletin	SB ALF502R 72-309	Allied Signal	Engine- Service evaluation of no. 1 bearing seal assembly.		Recommended at next shop visit…	SB ALF 72-342 SB ALF/LF 72-1082 FE - 2003
01/05/1996		Service Bulletin	SB ALF 72-329		#3 bearing			ALF 72-30-43
01/04/1995		Service Bulletin	SB ALF 502R 72-340	Allied Signal	Improved # 1 bearing assembly	Engine oil diffuser failure - Improved #1 bearing assembly.		Ansett mods, 1997 SB ALF/LF 72-1082 FE - 2003
01/05/1995		Service Bulletin	SB ALF502R 72-342	Allied Signal	Engine- Introduction of improved no. 1 bearing seal.	**Reason**: To introduce an improved carbon seal assembly… the new secondary seal is made of a more stable material which will help maintain equal force on all areas of the seal contact surface and reduce carbon element wear.	Recommended at operators convenience	ALF 72-30-39 ALF 72-30-60 SB ALF/LF 72-1082 FE -2003
		Service Bulletin	SB ALF 72- 842	Allied Signal				
		Service Bulletin	SB ALF 72- 843	Allied Signal				
		Service Bulletin	SB ALF 72-1002	Allied Signal				
05/12/1995	01-12-97 Rev 2	Service Bulletin	SB ALF/LF 72-1009	Allied Signal	Engine- Introduction of an improved No. 2 seal assembly.	**Reason**: New No. 2 seal assembly, incorporating a metal carbon retainer which reduces the potential for seal damage during installation and eliminates seal sticking.	Recommended at operators convenience	ALF 72-30-49

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		Service Bulletin	SB ALF 72-1010	Allied Signal	Improved # 1 oil seal.	Engine bearing / seal failure - improved # 1 oil seal.		SB ALF SB 72-340 SB ALF SB 72-342 SB ALF/LF 72-1082 FE -2003
		Service Bulletin	SB ALF 72-1011	Allied Signal				
		Service Bulletin	SB ALF 72-1018	Allied Signal		#3 bearing		ALF 72-30-43
28/06/1996		Service Bulletin	SB ALF/LF 72-1019	Allied Signal	Engine- Inspection of air diffuser assemblies with suspect welds on oil tubes.	**Reason**: Oil tube assembly kit…, contain suspect oil feed tubes and oil scavenge tubes… welds could eventually crack & cause oil leakage which results in "odour in cabin".	Recommended at 1st access to affected part, not to exceed 7500 cycles…..	
09/10/1996		Service Bulletin	SB ALF/LF 72-1027	Allied Signal	Engine- Replacement of diffuser curl assembly part...	**Reason**: Difuser curl assmebly part no. …was fabricated using tooling that makes the part… shorter in critical length than originally designed… potential interference… can result in damage to the air diffuser assembly scavenge oil tube…	Recommended at 1st access to affected part	
12/03/1997		Service Bulletin	SB ALF/LF 72-1034	Allied Signal	Engine- Introduction of an improved NO. 2 bearing.	**Reason**: New no. 2 bearing part…	Recommended at operators convenience	SB ALF/LF 72-1009

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01/01/1997		Service Bulletin	SB ALF 507 72-1035	Allied Signal / Honeywell	Engine-Introduction of improved air diffuser assembly with new oil tubes and double clamping	(due incorrectly manuf diffuser curls). **Reason:** Introduce improved pressure and scavenge oil tube/pan and clamp replacement… in the air diffuser assembly. This improvement will significantly reduce the possibility of an oil leak in the air diffuser area	Recommended at next shop visit when air diffuser assembly exposed	ALF 72-30-50
		Service Bulletin	SB ALF 72-1037	Allied Signal		# 2 bearing seal failure-removal of coking for oil passages- Increase heat shield to decrease coke build up.		
20/10/2000		Service Bulletin	SB ALF/LF 72-1058	Allied Signal		**Reason**: Existing air diffuser assembly oil pressure & scavenge tube clamps have shown deterioration from heat. Improved air diffuser clamps.	Recommended at next shop visit when air diffuser assembly exposed	
04/08/2003		Service Bulletin	SB ALF/LF 72-1082 FE	Honeywell	Field evaluation for the incorporation of a new No 1 seal part No 2-313-076-01 and No 1 seal faceplate part No 2-313-084-01	**Reason**: Problem. Current No. 1 seal and faceplate assembly may develop leaks allowing engine oil to enter the high pressure compressor airstream during engine operation.		SB ALF502R 72-309 -1995 SB ALF502R 72-342 -1995 SB ALF 502R 72-340 -1995 SB ALF 502R 72-1010 -??

13/12/1984		Service Bulletin	SB GTCP36-49-5563	Allied Signal, Garrett APU Division	APU- Incorporate improved inlet duct sealing	**Reason**: Due to the irregular configuration in the APU accessory drive gearbox oil sump area it has been difficult to provide uniform sealing around the APU accessory drive gearbox oil sump. A compound has been approved that will provide improved, uniform sealing.		BAe SB 49-10
13/12/1984		Service Bulletin	SB GTCP36-49-5562	Allied Signal, Garrett APU Division	APU- Incorporate improved compressor seal assembly.	**Reason**: Examination of APU's returned from service indicate that oil leakage can occur in the area of the compressor housing attachment bolts and past the compressor seal internal packing.		BAe SB 49-13
01/07/1991		Service Bulletin	SB GTCP 36-49-5592	Allied Signal, Garrett APU Division				BAe SB 49-16

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11/12/1989	01-11-90 Rev 2	Service Bulletin	SB GTCP36-49-5899	Allied Signal, Garrett APU Division	APU- Replace compressor seal assembly.	**Reason**: Problem- the current compressor seal has shown an unacceptable rate of failure which can result in smoke in the cabin. **Background**: The failure of the compressor seal assembly allows gearbox oil to leak into the compressor inlet , resulting in smoke in the cabin. The new seal has been redesigned to to improve sealing characteristics and reliability.		
		Service Bulletin	SB GTCP 36-49- 6573	Allied Signal, Garrett APU Division	APU- Stiffened exhaust flange to reduce leaks	**Reason**: Turbine housing flange leaks Background: Operators have reported exhaust gas carbon…	Recommended at next part access	
		Service Bulletin	SB GTCP36-49 6591	Allied Signal, Garrett APU Division				
01/10/1991		Service Bulletin	SB GTCP36-49 6595	Allied Signal, Garrett APU Division		Revised oil dipstick to avoid overfilling / oil leakage.	Recommended at next available opportunity	SB GTCP36-49

28/02/1992		Service Bulletin	SB GTCP36-49-6640	Allied Signal, Garrett APU Division	APU- Rework oil cooler fan assembly part...	**Reason**: Problem: Smoke/odour in the cabin can be caused from oil contamination in the APU compartment. Oil leaking past the fan assembly seal can enter the inlet plenum & mix with the bleed air. **Background**: There have been recurring reports from the field of smoke/ odour in the cabin when bleed air is selected on. Contamination in the compartment can enter the bleed air through any unsealed opening in the inlet plenum. An improved fan seal and rotor have been designed to reduce fan seal leaks which could lead to oil contamination of the bleed air.	Recommended at next part access	

28/02/1992		Service Bulletin	SB GTCP36-49-6641	Allied Signal, Garrett APU Division	APU- Authorisation for use of oil cooler fan assembly. APU generator cooling fan leakage.	**Reason**: Problem: Smoke/odour in the cabin can be caused from oil contaminationin the APU compartment. Oil leaking past the fan assembly seal can enter the inlet plenum & mix with the bleed air. **Background**: There have been recurring reports from the field of smoke/ odour in the cabin when bleed air is selected on. Contamination in the compartment can enter the bleed air through any unsealed opening in the inlet plenum. An improved fan seal and rotor have been designed to reduce fan seal leaks which could lead to oil contamination of the bleed air.		AR5 49-20-33 BAe SB 49-38 Ansett mods 1993 - 1996

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21/04/1992	Sep, 1993 Rev 5	Service Bulletin	SB GTCP36-49-6661	Allied Signal, Garrett APU Division	APU- Rework pneumatic and shaft gas turbine engine by incorporating an ejector system and bellows type compressor inlet seal assembly.	**Reason**: Compressor seal leaks which result in oil smoke/smell in the cabin. When the APU is running, smoke in the cabin can result from oil leaking past the APU compressor seal. Oil can leak past the seal as a result of rotating group vibration, a leaking packing seal or cocked oil between the seal and rotor interface.	Allied Signal recommends that this SB be done at the operators convenience	
		Service Bulletin	SB GTCP36-49-6691	Allied Signal, Garrett APU Division				
01/10/1995		Service Bulletin	SB GTCP36-49-7158	Allied Signal		Oil level sight gauge.		Honeywell SB 36-49 Ansett mods-1996-1999
Aug-96		Service Bulletin	SB GTCP36-49 7285	Allied Signal		Improved cooling fan for compatibility with ejector mods.		
Aug-98		Service Bulletin	SB GTCP36- 49-7346	Allied Signal		Improved compressor shaft seal.		
Feb-01		Service Bulletin	SB GTCP36- 49-7564	Allied Signal		Improved generator pad seal part- which had been considered a contributory factor in APU oil leakage	Recommended at 1st APU return for any cause	BAe SIL 49-24
Feb-98		Service Bulletin	SB GTCP36- 49-7346	Allied Signal				BAe SIL 49-24

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01/12/1984		Service Information Leaflet	SIL 21-7	BAe	Oil contamination of Air Conditioning System			Superseded by SIL 21/30 in January, 2000
18/04/1989		Service Information Leaflet	SIL 21/20	BAe	Air Conditioning-Bleed air system leaks.			
22/05/1989	6/01/95 Rev 4	Service Information Leaflet	SIL 21-21	BAe	Air Conditioning Pack-Health Monitoring & Cleaning	Engine & or APU compressor seal failure can cause oil contamination of the bleed air supply to the air conditioning pack. In turn contamination of the air conditioning packs can lead to hot oil smells in the passenger cabin and flight deck, and subsequent failure of the packs... Operators should note that cleaning procedures outlined in this document will not cure the problems caused by oil contamination of the air conditioning packs. Every effort should therefore be made to trace and eliminate the source of the contamination (SIL 21/30 refers)		
		Service Information Leaflet	SIL 21-22	BAe	Unknown (ref CAA MOR 199101548)			
28/09/1990	20/02/91 Rev 2	Service Information Leaflet	SIL 21-27	BAe	Oil contamination of Air Conditioning System	Operators have been reporting an increasing number of hot oil smells in the passenger cabin.		

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12/09/1991	12-08-94, rev 3	Service Information Leaflet	SIL 21/30	BAe	Air Conditioning- Cabin & flight deck mal odours - trouble shooting	Contamination of the air conditioning system can lead to mal odours in the passenger cabin and flight deck areas. The possible sources of contamination of the air conditioning system are: oil contamination of the bleed air supply due to an engine oil gallery diffuser failure or an engine shaft seal failure, oil contamination of the APU bleed air supply due to an APU shaft seal failure or APU inlet ingestion of APU bay contaminants.		
07/12/1993		Service Information Leaflet	SIL 21-33	BAe	Air Conditioning- In service evaluation of ECS filtration system to contain cabin smells.	Filtration system has been very effective in containing cabin/ flight deck odours		
21/09/1994		Service Information Leaflet	SIL 21-34	BAe	Air Conditioning- Air conditioning filtration system update.	The air conditioning filtration system... Is designed to remove excess oil & odour that, under certain failure conditions, may exist within the air conditioning system.		

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01/11/2000	01-01-01 Rev 1	Service Information Leaflet	SIL 21-45	BAe	Cabin air quality trouble shooting advice & relevant modifications.	This SIL describes modifications related to the subject of cabin air quality, best practice for trouble shooting and recommended actions after a cabin air quality event. Includes scheduled maintenance recommendations, troubleshooting sources, crew medical tests, post event maintenance and health monitoring, modifications...		
01/10/2001		Service Information Leaflet	SIL 21-47	BAe	Air conditioning-Advice relevant to Mandatory SB 21-150.			
		Service Information Leaflet	SIL 21-54	BAe	unknown ref CAA MOR 198900370 (1989 or before)			

29/01/1990		Service Information Leaflet	SIL 36/9	BAe	Pneumatics- Installation of catalytic converters in the bleed air system	In service complaints of contamination of the air conditioning system by oil originating in the engines, led to the introduction of catalytic converters into the bleed air system… recent failure of some catalytic converters has led to a complete review of this modification, cause of failure being attributed to a quality problem with an initial batch of CC's. This led to the introduction of a new CC. Introduction of the CC has been very successful in reducing contamination of the cabin air conditioning system by free air borne oil originating in the engines circulating through the bleed air system.		
		Service Information Leaflet	SIL 36-11	BAe	Bleed air hogging			

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19/08/1994		Service Information Leaflet	SIL 36/20	BAe	Pneumatics- Introduction of K & S Enterprises E-Last-O seals in place of Bestobell seals.	Investigation of in-service reoports of leaks from the pneumatic ducts has idnetified that many of these leaks are as a result of worn or damaged duct seals… Bestobell seals have twice the bearing surface area which improves sealing capability and reduces wear, increasing service life.		
31/08/1984		Service Information Leaflet	SIL 49/1	BAe	APU- Taping of APU plenum chamber-	It is possible for APU bay fumes to be ingested by the APU and enter the aircraft cabin through the air conditioning system if the sealing between the APU gearbox and intake plenum is inadequate.		
01/12/1984		Service Information Leaflet	SIL 49-3	BAe	Migration of oil from Generator / Adaptor to APU.	If the APU becomes overfilled with oil, the temperature of the oil can rise to a level that would damage seals and lead to contamination of the air conditioning system.		
31/01/1991	12-08-94 rev 3	Service Information Leaflet	SIL 49-14	BAe	Alternative APU flexible duct assembly	The new metal duct eliminates the possibility of duct failure caused by heat/oil contamination, which has been linked to cabin smells when bleed air is supplied by the APU		BAe SB 49-36, SIL 21/30

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01/09/2001	01-09-01 rev 1	Service Information Leaflet	SIL 49-19		APU- Trouble shooting high oil consumption for the honeywell APU equipeed with ejector system.			
14/02/1996	01-09-01 rev 2	Service Information Leaflet	SIL 49-22	BAe	APU: Oil smell in cabin- Maintenance alert- gear box vent tube.	A restriction or obstruction of the Sunstrand APU APS 1000 APU gearbox vent tube will cause significant oil leakage past the compressor seal system during APU shutdown… subsequent operation of the APU may cause environmental conditioning system pack contamination resulting in cabin odours.		CAA MOR 199101548
08/08/2000	01-09-01 rev 2	Service Information Leaflet	SIL 49-24	BAe	APU: Honeywell APU 36-100 & 36-150. Incorporation of SB GTCP36-49-7564 & SB GTCP 36-49-7346	SB GTCP36-49-7564 contains instruction for incorporating an improved seal pad… The generator seal pad was considered a contributory factor in APU oil leakage… SB GTCP 36-49-7346 gives aproval and instructions to incorporate improved compressor seal assembly... enhancing seal life	BAe systems concur with Honeywell recommendations for modification…	Honeywell SB GTCP36-49-7564 - 2000, Honeywell SB GTCP 36-49-7346- 1998

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01/01/1997		Service Information Leaflet	SIL ALF/LF-8	Allied Signal	Oil consumption limits.	**Background**: Lower oil consumptin rate will provide early warning of deteriorating oil system seal(s) or oil leakage by other means.		
01/01/2001		Service Information Leaflet	SIL ALF/LF-34	Honeywell		Turbine Engine Oils		
05/02/1988		Commercial Service Letter	88R-001	Textron Lycoming	Blockage of the No. 3 bearing intershaft seal design passage.	The presence of oil, coke or carbon formation within the compressor shaft is an indication of seal leakage and has resulted in engine damage.		
01/01/1996		Service Information Leaflet	SIL 326	Sunstrand	APU gearbox vent tube - oil smell in cabin			
13/06/1973		Commercial Service Letter		Textron Lycoming	ALF502 - Oil system contaminant samples			
13/06/1986		Commercial Service Letter		Textron Lycoming	ALF502 - Oil system contaminant samples - replaces CSL of 13/6/73			
17/06/1987		Commercial Service Letter		Textron Lycoming	ALF502 - Main engine oil filter analysis	Oil filter analysis is an effective tool for deducting wear of wetted components such as bearings & gearing		
01/11/1990		Operations Manual		BAe	Emergency Procedures / Fire Protection: Smoke from air conditioning system.	Protection from smoke / fire		

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01/01/2001		Manufacturers Operations Manual	Notice to Aircrew (2.00.07) Operational Notice: NO.OP.16 & 43 (Issue 1)	BAe	Smoke and Fumes	The air supply is protected from contamination by seals, which achieve maximum efficiency during steady state operation. However, they may be less efficient during transients (engine acceleration or deceleration) or whilst the engine is still achieving an optimum operating temperature. Improvements in seal design continue to increase efficiency, and when available, modifications are provided for the engines and APU.		
01/01/1999		All Operator Message	Ref 99/020V	BAe		Risk of affection by CO_2 / dry ice.		
01/01/1999		All Operator Message	Ref99/024V	BAe		Immediate use of oxygen mask when smoke or abnormal smell appears in cabin.		
05/01/2001		All Operator Message	Ref 00/030V	BAe	Smoke and Fumes (smells)	This AOM accompanies the forthcoming issue of Notice to Aircrew NO. OP 43 (BAe 146) and NO. OP16 (Avro RJ)… During the last year there have been several reports of the appearance of smoke or fumes originating from the air conditioning system…		

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14/02/2001		All Operator Message	Ref: 01/0004V	BAe	Revision of BAe146 and AVRO RJ MOM Vol. 3 - Abnormal and Emergency Checklist - Smoke and Fumes.	The ammendement will consist of the addition of the word FUMES to all titles for the relevant smoke drills...		
21/03/2001		All Operator Message	Ref 01/010V	BAe	Advance notice of mandatory inspection Service Bulletin 21-150			BAe ISB 21-150
01/04/1998		Internal engineering order / engineering release	AR5 49-10-4	Ansett / Allied Signal		Silicone rubber gasket between APU inlet flange & duct interface to prevent reingestion of exhaust gases.		Ansett mods - 5/98-8/99 TA 21070
01/11/1993		Internal engineering order / engineering release	AR5 49-20-33	Ansett / Allied Signal		Ejector system to reduce gearbox pressure which prevents oil leaking past compressor carbon seal- Known cause of smells in cabin.		SB GTCP36-49-6661 Ansett mods-11/94 - 10/96
		Internal engineering order / engineering	AR5 49-20-36	Ansett / Allied Signal		Bleed air supply contamination.		BA6 49-002
01/06/1996		Internal engineering order / engineering release	AR5 49-90-4	Ansett / Allied Signal		Oil level sight glass in lieu of dipstick to improve oil management.		Honeywell SB 36-49, SBGTCP36-49-7158 Ansett mods 5/98-7/99- 9 units modified
01/01/2050		Internal engineering order / engineering release	AR5 49-50-3	Ansett / Allied Signal		Improved APU bay ventilation / cooling fan oil leak- cooling fan leak is known cause of cabin smells.		

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		Internal engineering order / engineering release	AR5 49-80-1	Ansett / Allied Signal		Extra sealing compound at APU exhaust to aircraft interface to prevent contamination in APU bay- prevent possibility of exhaust gases being reingested & causing cabin smells.		BA6 49-80-1
		Internal engineering order / engineering release	ALF 72-30-33	Ansett / Allied Signal		Introduce improved #9 seal assembly. Priority 4		SB ALF 72-258
		Internal engineering order / engineering release	ALF 72-30-38	Ansett / Allied Signal		Introduces improved pressure and scavenge oil tube/pan in th galleries in the air diffuser - superseded		
		Internal engineering order / engineering release	ALF 72-30-39 ALF 72-30-60	Ansett / Allied Signal		Introduces improved # 1 position carbon seal assembly. Priority 2		SB ALF 72-342 SB ALF 79-1010
		Internal engineering order / engineering	ALF 72-30-43	Ansett / Allied Signal		New # 3 bearing introduced to minimise wear & improve engine reliability.		SB ALF/LF 72-1018 SB ALF502R 72-329
01/06/1997		Internal engineering order / engineering release	ALF 72-30-49	Ansett / Allied Signal		Introduces improved # 2 seal assembly which incorporates a carbon retainer. Priority 3.		SB ALF 72-1009

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01/09/1997		Internal engineering order / engineering release	ALF 72-30-50	Ansett / Allied Signal		Introduces additional improvements to the pre & post modification diffuser assemblies and supersedes ALF 72-30-38 - Priority 1.		SB ALF 72-1035
01/10/1992		Internal engineering order / engineering release	BA6 21-20-15	Ansett / BAe		Introduction of filtration system.		BAe SB 21-70, 21-71, 21-72 Ansett mods-11/92 - 12/92
		Internal engineering order / engineering release	BA6 21-20 –18	Ansett / BAe		Differential pressure check on ECS filters to provide feedback on condition of in service filters. (check every 300 cycles / filters changed not exceeding 1000 cycles / or when cabin smell reports persist).		
01/06/1993		Internal engineering order / engineering release	BA6 21-20-19	Ansett / BAe		Introduction of filtration system.		Ansett mods- 7/95 - 10/95
01/11/1994		Internal engineering order / engineering release	BA6 21-20-26	Ansett / BAe		Removal of coalescers.		BAeSB-21-70, 21-77 Ansett mods 4/97-11/97

		Internal engineering order / engineering release	BA6 21-20-28	Ansett / BAe		Periodic cleaning of air con ducting – removed & in situ detergent washing of ducting will prevent accumulation of dirt & oil contamination (every 4000 flight hours or after serious oil contamination incident or when reports of cabin smells persist).		
		Internal engineering order / engineering release	BA6 21-20-29	Ansett / BAe		Ducting replacement due oily deposits in internal insulation that cannot be cleaned by cleaning or pack burnout- (replaced every 4000 cycles).		
01/01/1997		Internal engineering order / engineering release	BA6 21-20-31/33/35/36/37/38/39 1997 to 1999	Ansett / BAe		Internal ventilation modifications.		Ansett intro 97-99 - due for compl 10/00 BAe 146 Air conditioning system modification program.
		Internal engineering order / engineering release	BA6 21-50-9	Ansett / BAe		Torque on ACM checked to determine in service condition of unit- every 3000 flights or TQ > 5 lbf / in.		

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		Internal engineering order / engineering release	BA6 53-20-20	Ansett / BAe		Additional sealing at interface between hydraulic bay sidewalls passenger cabin floor… To reduce to an absolute minimum the risk of fume transfer between the hydraulic bay and passenger cabin.		
01/12/1989		Internal engineering order / engineering release	BA6 36-10-11	Ansett / BAe		Remove engine / APU catalytic converters.		BAe SB 21-70, SB 71-34, 71-44 Ansett completed 7/95
01/07/1995		Internal engineering order / engineering release	BA6 36-10-17	Ansett / BAe		Reintroduce APU catalytic converter.		BAe SB21-72, SB 21-77, SB36-13, SB 36-28, BA6 21-20-26 Ansett mods 1997
		Internal engineering order / engineering release	BA6 36-10-20	Ansett / BAe		Bleed air hogging is major problem on BAe 146.		
		Internal engineering order / engineering release	BA6 38-30-3	Ansett / BAe		Modifications to toilet air extraction systems.		
01/02/1994		Internal engineering order / engineering release	BA6 49-00-2	Ansett / BAe		Modified 150M APU that incorporates ejector system-intro.		BAe SB 49-38 Ansett mods - 2/96-3/98

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01/04/1994		Internal engineering order / engineering release	BA6 49-00-3	Ansett / BAe		Introduce improved APU bay ventilation to decrease bay temp & help reduce auto shutdown intro.		BAe SB 49-35 Ansett mods - 1/97-2/98
01/02/1996		Internal engineering order / engineering	BA6 49-00-4	Ansett / BAe		Replaces 100MAPU with 150M APU with ejector system-intro 2.		Ansett7/96-2/98
01/11/1992		Internal engineering order / engineering release	BA6 49-80-1	Ansett / BAe		Extra washers at APU exhaust to prevent exhaust gas leakage into APU bay & reingestion causing smell inside cabin.		SB 49-30 Ansett 92-98
		Internal engineering order / engineering release	BA6 52-50-1	Ansett / BAe				
		Trial release/order	TA 21070 / 21191 / 21243	Ansett / BAe		Silicone rubber gasket introduced on trial basis between APU inlet shroud & duct interface (3 units) - so as to prevent APU reingesting exhaust gases from APU bay - In service evaluation.		AR5 49-10-4
01/07/1996		Trial release/order	TR 72-842/843	Ansett / BAe		Improved installation procedure bearing #2.		

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01/05/1990		Service Bulletin Environmental Control System Modification	SB ECS 01087A	BAe		Ram air duct improvements to prevent leakage.		
01/05/1990		Service Bulletin Environmental Control System Modification	SB ECS 50095A	BAe		Fume extraction for aft galley.		
01/05/1990		Service Bulletin Environmental Control System Modification	SB ECS40002M	BAe		Introduction of air outlets forward toilet.		
01/05/1999		Service Bulletin Environmental Control System Modification	SB ECS 40424H-K	BAe		Cabin airflow enhancements.		
01/07/1999		Service Bulletin Environmental Control System Modification	SB ECS 40424L	BAe		Cabin airflow enhancements.		

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01/09/1994		Service Bulletin Environmental Control System Modification	SB ECS 01343 A/B/C	BAe		Improved duct joints in bleed air supply.		
01/09/1998		Service Bulletin Environmental Control System Modification	SB ECS 01627A	BAe		Introduction of duct clamp assembly.		
01/07/1998		Service Bulletin Environmental Control System Modification	SB ECS 40424 A-G	BAe		Cabin airflow enhancements.		
01/07/1991		Service Bulletin Environmental Control System Modification	SB ECS 65188M	BAe		Introduction warm air outlets / aft vestibules.		
01/09/1994		Service Bulletin Environmental Control System Modification	SB ECS 01343 A/B/C	BAe		Improved duct joints in bleed air supply.		
			EMM 72-00-00			#1 engine bearing seal failure.		
			CMM 49-20-00	Honeywell				

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			CMM 21-50-20	NGL		Cleaning components of air con packs.		BAe SIL 21-45
		Maintenance Manual	Maintenance manual # 1780 - section 8	Normalair Garrett				SIL 21/7-1984
01/04/2001		Engine Manual	Engine Manual ALF502R -Temporary Revision No. 72-888	Honeywell	To revise the oil leakage inspection procedures.			
01/08/1997		Operations Manual	Notice to BAe 146 Pilots 37/97	NJS	BAe 146 / Avro RJ - Air conditioning contamination.	Troubleshooting odours… This is not a new phenomenon and all aircraft air conditioning systems will induce foreign odours(ie: oil or fuel) on occasions during routine operations.		
01/10/1997		Operations Manual	Notice to BAe 146 Pilots 52/97	NJS	BAe 146/ Avro RJ -Air conditioning system	Operate in Fresh mode.		
01/10/1997		Operations Manual	Notice to BAe 146 Pilots 58/00	NJS	BAe 146/ Avro RJ -Air conditioning contamination	Operate in Fresh mode.		NOTOP 09/98, 23/99
01/10/1999		Engineering notice	BAe 146/21/002-R1	NJS	BAe 146 air conditioning - contamination			
01/04/2001		Engineering notice	BAe 146/21/002-R2	NJS		Cabin oil smell identification / rectification flow chart in revision 1 superseded by AD ISB 21-150		
04/03/1998		Internal Memo		NJS	Oil odours in cabin.			

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01/05/1998		Inter office memo		Ansett		Air conditioning pack burns: Operation of the air conditioning system, in hot mode, following reports of cabin odours can be accomplished to help purge residual oils from the air conditioning packs and ducting.		
30/03/2001		Airworthiness Directive	AD 146/86	CASA / BAe 146	Inspection for engine oil seals, APU & ECS for signs of oil contamination.	...Cabin air quality has been the subject of intense investigation for a number of years… While overseas operators have experienced cabin air contamination events, these events have not generally been treated with the same degree of concern, as is the case with Australian operators. Consequently, overseas operators have not been as active in introducing the cabin air quality improvements into their aircraft.	**Mandatory**: CASA: BAe ISB 21-150	BAe ISB 21-150

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21/03/2001		Airworthiness Directive	AD 002-03-2001	CAA / BAe 146 (100, 200 & 300 series)	Air conditioning: To inspect engine oil seals, APU & ECS Jet pump and air conditioning pack for signs of oil contamination	Action required because incidents have been reported of impaired performance of flight crew… events could have been caused by inhalation of agents… leaking from oil or APU and contaminating the Environmental control system.	**Mandatory**: CAA: BAe ISB 21-150	BAe ISB 21-150
28/11/2002		Airworthiness Directive	AD /BAe 146/102	CASA / BAe 146 (100, 200 & 300 series)	Air Conditioning - Duct inspection.	It is found that the sound attenuating material used in the air-conditioning ducts can absorb oil and can become a source of persistent air contamination. CAA(UK) has classified the requirements of BAE Systems ISB. 21-156 as Mandatory.	**Mandatory**: CASA: BAe ISB 21-156	BAe ISB 21-156
19/12/2002		Airworthiness Directive	AD 003-10-2002	CAA / BAe 146 (100, 200 & 300 series)	Air Conditioning- Inspect air conditioning sound attenuating ducts for signs of oil contamination.	The Service Bulletin requires an inspection of the inside of each of the four air conditioning sound-attenuating ducts for the presence of oil contamination. This action is required because incidents have been reported of impaired performance of flight crew...	**Mandatory**: CAA: BAe ISB 21-156	BAe ISB 21-156

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14/07/2004		Airworthiness Directive	AD 2004-12-05	FAA / BAe 146 (100, 200 & 300 series)	Air conditioning sound-attenuating duct	This amendment adopts a new airworthiness directive (AD), applicable to all BAE Systems (Operations) Limited Model BAe 146 series airplanes, that requires repetitive detailed inspections of the inside of each air conditioning sound-attenuating duct, and corrective actions as necessary. This action is necessary to prevent impairment of the operational skills and abilities of the flightcrew caused by the inhalation of agents released from oil or oil breakdown products, which could result in reduced controllability of the airplane. This action is intended to address the identified unsafe condition.	**Mandatory**: FAA:BAe ISB 21-156	
29-May-03		Airworthiness Directive	AD /BAe 146/105	CASA / BAe 146 (100, 200 & 300 series)	APU- Air inlet duct modification.	To prevent contamination of cabin air due ingestion of oil from APU bay. Carry out modification per BAE Systems SB. 49-036-36019E, Rev 4, Dated 30 April 2003. This service bulletin has been classified as mandatory by UK-CAA.	**Mandatory**: CASA Carry out modification per BAE Systems SB. 49-036-36019E, Rev 4, Dated 30 April 2003.	BAe SB 49-036 6 Jul, 1993 (optional)

19-May-03		Airworthiness Directive	AD 007-04-2003	CAA / BAe 146 & 146/RJ (with selected mods)	APU- Improved APU inlet flexible duct Part No. DXA07175	The Service Bulletin introduces a rectangular metallic bellows duct incorporating an improved seal and clamp arrangement as a direct replacement for the rubber bellows duct. This action is required because the existing APU inlet duct and sealing arrangements have been found to be unreliable in service. This can result in APU bay air being ingested, which if contaminated can lead to poor cabin air quality.	**Mandatory**: CAA Compliance is required with BAE Systems (Operations) Service Bulletin SB.49-036-36019E at Revision 4	BAe SB 49-036 6 Jul, 1993 (optional)
02/03/2005		Airworthiness Directive	AD/BAe 146/105 Amdt 1	CASA / BAe 146	APU- Air inlet duct modification.	Carry out modification per BAE Systems SB. 49-036-36019E, Rev 5, Dated 27 July 2004. Contamination of cabin air due to the ingestion of oil from the APU bay is found to occur on the affected aircraft. This modification provides an improved seal at the aircraft - APU interface to prevent this. Rev 5 of the reference document introduces replacement of the bellows attachment hardware.	**Mandatory**: CAA Carry out modification per BAE Systems SB. 49-036-36019E, Rev 5, Dated 27 July 2004.	BAe SB 49-036 6 Jul, 1993 (optional) AD 146/105- 2003