

Aircraft Air Quality Malfunction Incidents: Design, Servicing, and Policy Measures to Decrease Frequency and Severity of Toxic Events

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Abstract Aircraft air supply contamination from leaking oil and hydraulic fluids has a long history in commercial aviation. There is a wide range of aviation legislation covering the required processes to be followed when this type of defect occurs, including reporting, maintenance procedures, airworthiness requirements, crew fitness for flight and emergency procedures. A variety of evidence showing that contaminated air has an extensive and well-documented history will be examined. It is clear that the regulations are not being adhered to or enforced. A variety of issues emanating from these failures will be reviewed as well as suggestions made as to what can be done to effectively resolve them.

Keywords Aircraft air contamination · Airworthiness standards · Jet oil leaks · Fumes · Aircraft defects · Aircraft modifications

Abbreviations

AD Airworthiness directive
AOM All operator message
APU Auxiliary power unit

ATA	Air Transport Association
BaE	British Aerospace
CAA	Civil Aviation Authority (UK)
CASA	Civil Aviation Safety Authority (Australia)
ER	Engineering release
FAR	Federal Aviation Regulation
JAR	Joint Aviation Regulation
ICAO	International Civil Aviation Organisation
MEL	Minimum equipment list
OHS	Occupational health and safety
SB	Service bulletin
SIL	Service information leaflet or letter

1

Introduction

In assessing the design, servicing and repair policy measures to decrease contaminated air event frequency and severity, an appreciation of the regulatory aspects and development of aircraft pressurisation and air conditioning systems is necessary.

The safety issues relative to the supply of clean air in the cabin of a modern jet aircraft should be viewed in terms of the requirements of aviation legislation and the airworthiness standards that are required to enable the aircraft to be issued with a document called a Certificate of Airworthiness. This certification allows for subsequent and continuing operation.

Pressurisation in aircraft refers to the sealing of the cabin, the supply of air to it from an external source and the control of pressure. Pressurisation is needed in commercial aircraft that fly at high altitude because the human body requires a continual supply of oxygen, the quantity varying with the amount of physical effort. Pressurisation permits cabin altitudes to remain below 8000 ft. (about 2400 m) whilst the aircraft flies generally between 30 000 and 40 000 ft. (9100–12 100 m). Associated with pressurisation, the cabin atmosphere must be provided with an air conditioning system which is necessary because of the extremes of temperature in which an aircraft may be operating from day to day. An aircraft needs to be heated or cooled to maintain a temperature of approximately 22 °C, while in flight outside temperatures may be as low as – 60 °C.

Further, the creation and maintenance of a comfortable atmosphere requires a certain amount of fresh air to be provided for each person. A number of methods of supply of air for pressurization and air conditioning have been employed, such as engine-driven compressors, air-driven compressors and bleed air, in which some air that could be used for combustion in the engine is “bled off” for the cabin air supply. Additionally, since the 1970s, some air

has been recirculated. This involves the re-use of part of the used air from the cabin mixed with the incoming fresh air from the compressors, therefore reducing the fuel usage by reducing the amount of air bled off from the source.

2 Development of the Regulatory Framework

These design issues were recognised as components of an aviation safety system and so, to ensure international uniformity, like-minded countries met and formed the International Civil Aviation Organisation (ICAO) in 1944. ICAO developed certain protocols that contained the standards which all signatories states are obliged to uphold. Legislative backing by each member state is required to ratify the Organisation's protocols, with any non-compliances being notified to the ICAO Secretariat.

International airworthiness standards set down by ICAO detail what is required for an aircraft to be deemed "fit for flight" or "airworthy" and each

Table 1 Development of airworthiness standards to enable safe operation of the aircraft

Type design	Specification of appropriate design specification
Type certification	Aircraft or product conforms to the appropriate design document Type data certificate sheet (aircraft) Supplemental type certificate (aviation product) Technical service order (equipment or component). Parts manufacturing authority (part or component)
Production approval	Manufacturing approvals
Operational approvals	Registration of aircraft in the national register Certificate of airworthiness (certificated aircraft) Special flight permits (non-certificated aircraft) Maintenance release/return to service issuance (dependent on certificate of airworthiness or flight permit)

country adopts these design aspects into its own legislation [1]. The national regulations for many countries will parallel or be harmonised with the ICAO requirements of the US Federal Aviation Regulations (FAR) and European and UK Joint Aviation Regulations (JAR) [2]. Airworthiness standards cover, among other things, aircraft design, aircraft materials, engines and auxiliary power unit (APU) requirements, aircraft performance, fuel and oil systems, and aircraft ventilation [3].

The international airworthiness standards specified by the ICAO have been promulgated and distributed under ICAO Publication Annex 8 (“Airworthiness of Aircraft”) which expects the member state (country of registry) to effect design standards through appropriate instruments to give legislative backing to the standards and specifications.

Leading countries where aircraft manufacture occurs generally issue publications providing guidance on a range of subjects from “First-of-Type Aircraft Introduction Procedures” through to “Continuing Airworthiness” so as to ensure the ongoing safety of the product.

To assure the continuing airworthiness of any certificated product it was expected the framework in each ICAO member’s own country procedures would include a “Service Difficulty Reporting System” whereby operational or design problems could be brought to the attention of the appropriate authorities and the holder of the Type Certificate (or equivalent) so that the proper consideration and resulting action or product improvement could be implemented.

The development of airworthiness standards to enable safe operation of the aircraft can be summarised by the steps shown in Table 1.

3 Ventilation Regulations

An aircraft must be maintained in an airworthy state in order to fly. Many countries adopt Part 25 of US FARs and/or Part 25 of the JARs as the airworthiness standards for transport category aeroplanes.

The airworthiness standard for aircraft ventilation, developed in 1965 [4] with the latest amendment in 1997, is FAR/JAR regulation number 25.831, which requires that:

- 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 vapours.

- 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, pressurisation or other systems or equipment.

The airworthiness ventilation regulation for transport aircraft, FAR/JAR 25.831 a/b, established in 1965 [4, 5] is the major ventilation regulation that must be met for an aircraft to be considered fit for flight. Where exposure events occur as outlined in the previous chapter on frequency of events, part 25.831a is being ignored. With regard to part 25.831b, industry claims it is not known if the contaminants are at or above harmful levels despite no or inappropriate testing being carried out in flight to determine levels of contamination at the time of the leaks. Additionally, when the regulation came into effect, part b was thought to only cover carbon monoxide, carbon dioxide or ozone and all other contaminants were not considered [6]. Some regulators claim that aircraft toxicants are more of an occupational health and safety (OHS) issue than an air safety issue. For example, the UK Civil Aviation Authority (CAA) has recently advised [7] that crew discomfort such as headaches, nausea and irritation due to contamination is not its responsibility unless the safety of flight and landing are affected. This is not in the intent of airworthiness regulation 25.831a, which implies that undue discomfort and fatigue has the ability to affect crew performance and therefore could impair flight safety.

4

Sources and Examples of Defects Covering Contaminated Air From Lubricant and Fluid Leaks

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. 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 identify to all what the particular topic is. Some examples are ATA 21—Air conditioning; ATA 36—Pneumatics; ATA 49—Auxiliary power unit (APU); ATA 71, 72—Power plant general, engines. This information takes various formats explored later.

4.1

Service Bulletins

Service bulletins (SB) are based upon information gained from the field and are issued on a variety of compliance options. They are issued by the manufacturer identifying inspections or modifications that have been issued. The SB will list the title of the modification, effectivity, reason and in some cases background for its release, description, compliance, man-hours, costs and so on. In rare cases, these may be issued as an alert SB indicating a higher status. SBs may be issued for information only, optional or recommended, often with a statement as to when this might be undertaken. The manufacturer cannot make the modifications or inspections required by SBs mandatory.

The nonmandatory nature of such advice is problematic. Aircraft operators should take greater responsibility to assess whether a modification or inspection requirement ought to be implemented, as currently although operators subscribe to the SBs, the requirement to assess them is only implied and there is no requirement to act on advice in safety-related SBs [8]. On the British Aerospace (BAE) 146 for example, SBs from 1983 up until 2000 were all for information only, optional or recommended and usually at a time to suit the operator, except for one mandated in 1985 [9]. As such it is unknown how many will have been acted upon, but quite likely many will not have been undertaken as these are not mandatory.

It appears that many in the aviation industry view modifications and inspections for oil leaking into the air supply as part of its ongoing product improvement and enhancement [10], rather than as a mandatory requirement to meet the airworthiness regulations. Despite the BAe 146's long history of fumes, oil and hydraulic fluid leakage into the air supply and strong evidence of crew discomfort going back to at least 1983, and despite the fact that contaminated air breached the ventilation airworthiness requirements, no other SBs were made mandatory until 2000. Since 2000 only five SBs on three aircraft types have been made mandatory by the regulators in selected countries through their inclusion in airworthiness directives (ADs): the MD series aircraft [11]; the Rolls Royce 307 series engines [12]; and the BAe 146 [13–18].

Examples of SBs include:

- BAe—SB 49-5-35040G: 24 October 1984. Title: “APU—Introduce an improved compressor inlet duct seal”. 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” [19].

- Allied Signal, Garrett APU Division (BAe 146)—SB GTCP36-49-5899: November 1989. Title: “APU: Replace compressor seal assembly”. Reason: “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.” Compliance: “Recommended at operator’s convenience” [20].

Other SBs dealing with the air quality issue on the BAe 146 include Refs. [21–24].

4.2

Airworthiness Directives

A national regulator such as the US Federal Aviation Authority or the UK CAA can make a SB mandatory when it feels a significant or real safety issue exists or is likely to exist [10, 25], by issuing an AD. However, regulators have been reluctant to issue ADs in relation to contaminated air despite evidence and acknowledgement that breathing oils and fumes is “a potential threat to flight safety” and failure to meet the airworthiness ventilation when undue discomfort and fatigue is occurring associated with contaminated air [4, 13, 14, 23, 24]. This reluctance may be economically driven or may be due to a lack of expertise in this field as the regulators and manufacturers have admitted that toxicants in aircraft cabins are outside their field of expertise [26]: “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.” [10].

Compliance dates with mandatory ADs vary greatly, despite ADs being issued where a safety risk exists or could exist. While some ADs require inspections and possible maintenance before further flight or within 10 h provided the source of contamination can be identified and isolated following suspected oil contamination [13], others allowing smoke and odours into the cabin require modifications 36 months or more after the AD was issued [11]. In two cases service information data indicating oil contamination of the ducting in 1984 [27] and an optional SB in 1993 [22] indicating oil contamination of the APU inlet duct were made mandatory through ADs 18 and 10 years later, respectively [15–18]. An AD will list the details, background and a compliance date by which the requirements must be completed. In some cases months or years are assigned for completion.

Examples of an SB made mandatory by the regulator and an actual AD include:

- BAe—SB 21-150: 20 March 2001. Title: “Air conditioning—Inspect engine oil seals, APU and environmental control system jet pump and air condi-

tioning 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 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.” Compliance: “Mandatory” [23].

- CAA AD 003-10-2002 (BAe 146) December 2002 BAe SB 21-156. Title: “Air conditioning—Inspect air conditioning sound attenuating ducts for signs of oil contamination”. Reason: “Action required due to incidents reported of impaired performance of flight crew.” Compliance: “Mandatory” [15].

4.3

Service Information Leaflets or Letters

Service information leaflets (SIL) are information documents, usually issued to disseminate information generally supporting a SB-related modification or inspection.

Example of SILs include:

- BAe 146 SIL 21/7: December 1984. Title: “Oil Contamination of Air Conditioning System” [27].
- BAe 146 SIL 21/45: November 2000. Title: “Cabin Air Quality Trouble Shooting Advice and Relevant Modifications (includes sources of contamination, modifications, medical tests and crew health survey)” [28].

Other SILs dealing with the air quality issue on the BAe 146 include Refs. [29–32].

4.4

All Operator Letters or Message

All operator letters or all operator messages (AOM) are information sent by manufacturers to aircraft operators on a particular subject. An example of an AOM is:

- BAe AOM Ref 00/030V: January 2001. Title: “Smoke and Fumes”. Reason: “Measures to take when smoke or smell from air conditioning system is sensed ... 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” [33].

Table 2 Selected modifications and data available for review for the BAe 146 aircraft

Report type	Source	Year(s)	Number	Sources (see, for example)
Service bulletins aircraft manufacturer	BAe	1984–2003	85+	[19, 22–24]
Service bulletins engine	Allied Signal/ Honeywell	1984–2000	27+	[21]
Service bulletins APU	Allied Signal/Garrett APU Division Allied Signal	1984–2001	15+	[20]
Service information leaflet	BAe	1984–2001	20	[27–32]
Service information Leaflet	Allied Signal/Honeywell	1997 and 2001	2	[SIL ALF/LF-8]
All operator message	BAe	1999–2001+	6	[33]
Internal engineering releases/orders	Ansett (BAe/Allied Signal)	1992–1998	32	[BA6 21-20-29]
Various: EMM, CMM, MM, engineering notice, internal memo	BAe, Honeywell, Normalair/Garrett, NJS, Ansett	Various	9+	[38, 39]
Airworthiness directive	CASA, CAA—BAe 146	2001–2003	6+	[13, 14]
Total		1984–2003	202+	

4.5

Other Sources of Information

Other sources of information include defect reporting in the aircraft technical log, defect reports sent from the aircraft operator to the regulatory authority, informal communications between aircraft operator and manufacturers or defects reports to regulators from the Type Certificate holder.

Sources of information also include Manufacturer's Operations Manual/ Notices to Aircrew/Operators, which is information provided to operators and aircrew by the manufacturer highlighting operational information [35, 36]. Other records include engine maintenance manuals listing modification details and procedures such as engineering maintenance manuals revising oil leakage inspection procedures [37], notices to pilots regarding air conditioning contamination [38, 39], engineering updates or engineering releases (ER) such as the following:

- Ansett (Allied Signal) ER AR5 49-20-33: November 1993: "Ejector System to Reduce Gearbox Pressure which Prevents Oil Leaking Past Compressor Carbon Seal—Known Cause of Smells in Cabin: See SB GTCP36-49-6661 (work undertaken 11/94–10/96)"

4.6

A Case Study in Reporting Documentation: The BAe 146

Table 2 brings together the various documentation and reporting means described earlier and lists selected air quality/contaminated air related data in various formats for the BAe 146 and 146RJ aircraft and its engines, the ALF/LF 502/507. The table includes only revisions up to 2003 and includes data collected by the authors from a range of sources.

A number of issues are raised by reviewing the information in Table 2. Information is generally not available for review, difficult to source or the history of the problem is generally not clearly identified. For example, improvements made to a number one bearing seal in 1995 for the BAe 146 engine were still causing problems in 2003 [21, 39, 40], yet many in the industry believed that the problem was fixed. The various ADs raised between 2001 and 2003 did not clearly demonstrate the problems were well known many years earlier.

5

Regulatory Inconsistencies Indicating Health and Safety Issues

In some cases, aircraft air contamination modifications or inspections will relate to a maintenance or engineering issue. However, from first principles, oil

leaking into the aircraft air supply is a design issue, with initial certification clean air airworthiness requirements needing to be met as well as as on an ongoing “continuing airworthiness” basis throughout the aircraft’s operating life [3]. BAE acknowledged this in 2000 when advising that engine or APU seals may be less efficient during transients (engine acceleration or deceleration) and improvements in design when available would be provided [36]. However, a design fault that leads to ongoing engineering and operational problems is difficult to rectify, appears to be accepted fatalistically as costly to fix, and ultimately, often ignored.

The substantial amount of evidence regarding oil leakage and crew and passenger discomfort would indicate continuing airworthiness is not being maintained as oil and hydraulic fumes are not being viewed as part of the continuing airworthiness requirements. As shown in the contribution on rates (Michaelis/Winder in this volume) and Sect. 4 in this contribution, there is a very large and varied volume of industry modification and defect data available, directly related to oil leaks and contaminated air dating back over 20 years [34]. Moreover, industry information of effects of oil contamination dates back to at least 1981 [41]. Impaired crew performance was first documented in 1977 [42], with increasing reference to impaired crew performance in recent years. It is clear that the aviation industry has shown great reluctance to openly and satisfactorily deal with the issue.

Fumes (predominantly Mobil Jet Oil II leaking into the bleed air supply [43]) identified as oil leaking past the engine and APU oil seals [10, 44] have been seen as a nuisance rather than a potential threat to flight safety [23, 24]. Oil contamination and noxious fumes are not being regarded as a major defect or equivalent and are often not regarded as needing to be reported as required by the various regulations and therefore the subsequent requirements are not fulfilled, as the following examples show:

- “Prior to the issue of the AD by CASA, there was no specific requirement for National Jet Systems (NJS) to report to CASA on incidents of air contamination.” [45].
- “We don’t regard fumes as an immediate threat to aviation safety ... Obviously if we did we would have to ground flights.” [46].
- “Oil fumes are more of a health problem than an aircraft technical defect as not all pilots affected and there is no mandate to look at health.” [47].
- “Toxins in cabin air are an OHS issue and not responsibility of the Aviation Regulator which is responsible for short and medium term effects on safety.” [26].

In Australia, for example, the aircraft operators and the Civil Aviation Authority (CASA) have failed to view fumes and oil contamination as a major defect as required in its own legislation, manuals and advisories [48–50]. These issues are not being reported in all cases, as there is a failure to view the issue as an industry responsibility [26]. This is evidenced by the previous comments

showing that prior to the issue of the first BAe 146 air contamination related AD in March 2001, CASA did not view fumes as reportable or a safety issue. Comments by a major aircraft operator suggesting they are “different” as they require fumes to be reported [43] shows the industry indifference to the reporting system, which is clearly not working. Industry accepts that all engine oil seals can leak and that it is an inevitable feature of the design of air conditioning systems [26, 43]. However, it is recognised that no one modification is a complete fix: “The modifications will not solve the problem completely—they are to reduce the number of events.” and “The modifications that have been developed are really around the reliability of the seals and making sure they don’t fail as frequently. So they are improvements to the reliability, rather than improving the quality of the sealing.” [10].

A recent 2004 comment by CASA very importantly completely contradicts the industry perception that fumes are not reportable occurrences and turns around the long-held CASA position that such defects are not major defects and therefore not reportable: “All instances of smoke or fumes in the aircraft cabin that adversely affect the quality of cabin air on Australian registered aircraft ...are categorised by the CASA as a ‘Major Defect.’” [51].

Failures of oil seals are seen as the common factor in the majority of fume incidents [52–56] and are often hard to identify [52–57]. Inspections for oil leaks and fumes often take place between flights with engineering comments including “not safety of flight”, “no fault found”, “report further” or “repair at company convenience” with reports of fumes sometimes ongoing over days, weeks or months [52, 58, 59]. Factors involved include the difficulty in precisely locating the oil leak, cases where more than one engine or APU oil leak combination occurs and “residual contamination” of the air conditioning packs [52].

After air contamination by oil and hydraulic fluids on an aircraft it is common practice to continue to operate the aircraft with part of the bleed air supply or one aircraft air conditioning pack deselected under the minimum equipment list (MEL) system. However this does not take into account several important factors. There may be difficulty in accurately determining the exact source of the contamination; additionally “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.” [60, 61]; or “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 [60, 61].

Crews appear to be significantly under-reporting contaminated air events. Therefore, the true scale of the problem remains unknown and the issue is continually downgraded. Some examples include fumes not being seen as major defects or similar with compulsory reporting and under-reporting,

which is known to be occurring (as discussed in the chapter on rates of incidents) [53, 61–65]. Reasons for under-reporting include fumes being seen as a highly repetitive occurrence and almost as a normal part of flight, fear of reporting ongoing problems, lack of understanding of effects of fumes on the individual and regulatory requirements and crews being advised by company doctors that there are no adverse health implications. In addition to the reporting, airworthiness, defect and maintenance investigation regulations not being met, contaminated air affects crew fitness with regard to flight regulations and emergency procedures, such as the ability of the cabin crew to evacuate the cabin in 90 s.

Also, the use of emergency oxygen is not being seen as a serious incident, as established by the ICAO [66]. Fume contamination is clearly a safety deficiency by definition but as an example of the downgrading of the issue, the Australian Transport Safety Bureau stated it was a “possible safety deficiency” [52, 67, 68]. While the use of oxygen when contamination events occur is required for flight crew, it was only recently added to the emergency and abnormal procedures checklist. Previously oxygen was only required when smoke or fire occurred [33, 35]. Emergency 100% oxygen is not generally being used in short-term transient fume events which are part of the design problem, but are seen as a normal part of flight by pilots. At the same time, cabin crew and passengers are not provided with any effective protection against contaminated air. The UK CAA requires mandatory occurrence report to be made where oxygen is used in fume incidents, yet this was generally not occurring. It only recently advised crews to use oxygen in all fume events [69]; however, this is still not occurring in all cases and the reports are often not made. Additionally the subtle incapacitation effects of odourless gases or fumes such as carbon monoxide may not alert the pilots to the need to use oxygen.

6

Conclusion

There is a wide variety of legislation and data that support that engine oils and hydraulic fluids are leaking into the cabin air supply. There is increasing evidence to show this is affecting crew performance and health both short and long term. There is evidence going back many years clearly showing that oil and hydraulic leakage is a major ongoing problem and that the regulatory requirements are not being adhered to or enforced. These defects are in fact part of the ventilation airworthiness requirements and must continue to be met for an aircraft to be considered fit for flight. However, industry attitudes towards contaminated air have been complacent and irresponsible. “This is alarming, especially when it is apparent that commercial aircraft have no immediate or effective back-up system to protect crews and passengers should the “bleed air” become contaminated”, despite the technology existing that could address this

problem. This complacency has allowed the obvious safety implications of operating crew experiencing discomfort when exposed to oil fumes and the short- and long-term health implications continue for many years.

For a safety system to work effectively all the components of the system need to operate as designed. The lack of recognition of the full implications of the contaminated air problem with the BAe 146 and other aircraft models highlights the breakdown in the inter-relationships on which a properly functioning safety management system is dependent.

Steps to be taken to reduce this problem include the need to review clean air airworthiness requirements to cover all contaminants and view “undue discomfort and fatigue” as contrary to the legislation. It is necessary to view clean air under FAR/JAR 25.831a/b as part of ongoing aircraft certification requirements. Also, correct reporting and under-reporting problems must be resolved. All regulations including airworthiness ventilation regulation, defect reporting and maintenance procedures, fitness for duty and emergency procedures must also be met. Appropriate monitoring of aircraft air (during contaminated air events) for all hazardous compounds must take place and independent, appropriate testing of oils and their pyrolysis breakdown products must be undertaken. Less toxic oils ought to be used and a review of the toxicity of oils in terms of human inhalation in aircraft and the applicability of exposure standards should be undertaken. Continued flight under the MEL system when the air supply is suspected to be contaminated and crews show signs of discomfort should not occur. Modifications relating to contaminated air should be made mandatory as distinct from merely optional, for information, or recommended at operator convenience. All crew should use oxygen when air contamination occurs. The collation of data worldwide should take place so as to review major issues and trends.

There is a need to educate all within the industry, including crews, operators, manufacturers and regulators, that contaminated air must be reported and addressed immediately.

Better designed engine/APU bearing oil seals must be made a priority. Bleed air filters that are effective in removing applicable contaminants must be fitted and maintained to protect crews and passengers from contaminated air. Finally a review of “bleed air” systems and possible “bleed-free” systems such as being used on the Boeing 7E7 Dreamliner should be undertaken.

References

1. FAA/ASA (1997) Pilot's handbook of aeronautical knowledge. US Federal Aviation Authority/Aviation Supplies and Academics, Washington
2. CETS (1998) Improving the continued airworthiness of civil aircraft: a strategy for the FAA's aircraft certification standard. Commission on Aircraft Certification Safety Management. National Research Council, Washington

3. Hoy B (2000) What makes an aircraft airworthy? Flight Safety Australia, Civil Aviation Safety Authority of Australia, Canberra
4. FAA (1965) Federal aviation regulations, transport category airplanes, airworthiness standards—Ventilation section 25.831, February 1965 (amendment 25–87—effective 7 May 1996). US Federal Aviation Authority, Washington
5. JAA (2003) JAR airworthiness ventilation regulation 25.831a/b. Amendment 16 May 2003. <http://www.jaa.nl/section1/jars/430782.pdf>
6. Best R (2001) Certification of aircraft in Australia. Aviation air quality. In: Winder C, Michaelis S, Weber RO (eds) Proceedings of the Aviation Air Quality Symposium, Australian Defence Force Academy/University of New South Wales, 7 December 2000, University of New South Wales, Sydney, pp 78–82
7. Hamilton T (2004) Letter to British Airline Pilots Association (BALPA) Aircraft Environment Task Group. UK Civil Aviation Authority, London
8. Villiers D (2004) Watching brief. Flight Safety Australia, Civil Aviation Safety Authority of Australia, Canberra
9. BAe (1985) Service bulletin SB 21-24—00543A. British Aerospace Systems, Hatfield
10. BAe (2000) British Aerospace submission and evidence by British Aerospace Systems to the Australian Senate Inquiry into Air Safety (1999–2000) BAe 146 Cabin Air Quality. Parliament of Australia, Canberra
11. FAA (2000) Airworthiness directive (AD) 2000-15-17, MD series aircraft. US Federal Aviation Authority, Washington
12. FAA (2001) Airworthiness directive AD 2001-08-15: Rolls Royce 3007 series engines. US Federal Aviation Authority, Washington
13. CAA (2001) Airworthiness directive (AD) 002-03-2001: Air conditioning—To inspect engine oil seals, APU and ECS jet pump and air conditioning pack for signs of oil. UK Civil Aviation Authority, London
14. CASA (2001) Airworthiness directive AD/BAe 146/86: Environmental control system—Inspection for contamination. Civil Aviation Safety Authority of Australia, Canberra
15. CAA (2002) Airworthiness directive (AD) 003-10-2002: Air conditioning—To inspect air conditioning sound-attenuating ducts for signs of oil contamination. UK Civil Aviation Authority, London
16. CASA (2003) Airworthiness directive AD/BAe 146/102: Air-conditioning duct—Inspection. Civil Aviation Safety Authority of Australia, Canberra
17. CASA (2003) Airworthiness directive AD/BAe 146/105: APU—Air-inlet duct—Modification. Civil Aviation Safety Authority of Australia, Canberra
18. CAA (2003) Airworthiness directive (AD) 007-04-2003: Airborne auxiliary power (APU)—Introduction of improved APU inlet flexible duct part no DXA07175. UK Civil Aviation Authority, London
19. BAe (1984) Service bulletin SB 49-5-35040G: APU—Power plant—Introduce an improved compressor inlet duct seal (Garrett change 13). British Aerospace Systems, Hatfield
20. Allied Signal (1989) Service bulletin SB GTCP36-49-5899: APU: Replace compressor seal assembly. Allied Signal Aerospace, Phoenix
21. Allied Signal (1995) Service bulletin SB ALF502R 72-342. Allied Signal Aerospace, Phoenix
22. BAe (2003) Service bulletin SB 49–36: Airborne auxiliary power (APU)—Introduction of improved APU inlet flexible duct part no DXA07175. British Aerospace Systems, Hatfield (fourth revision). Original issue 1993

23. BAe (2001) Service bulletin SB 21-150: Air conditioning—To inspect engine oil seals, APU and ECS jet pump and air conditioning pack for signs of oil contamination. British Aerospace Systems, Hatfield
24. BAe (2002) Service bulletin SB 21-156: Air conditioning—To inspect air conditioning sound attenuating ducts for signs of oil contamination. British Aerospace Systems, Hatfield
25. CASA Australian civil aviation regulation 37A—Airworthiness directives. Civil Aviation Safety Authority of Australia, Canberra
26. CASA (2000) submission and evidence of the Civil Aviation Safety Authority of Australia to the Australian Senate Inquiry into Air Safety (1999-2000) BAe 146 Cabin Air Quality. Parliament of Australia, Canberra
27. BAe (1984) Service information leaflet SIL 21-7: Oil contamination of air conditioning system. British Aerospace Systems, Hatfield
28. BAe (2000) Service information leaflet SIL 21-45: Cabin air quality trouble shooting advice and relevant modifications. British Aerospace Systems, Hatfield
29. BAe (1990) Service information leaflet SIL 36/9: Installation of catalytic converters in bleed air system. British Aerospace Systems, Hatfield
30. BAe (1990) Service information leaflet SIL 21/27: Oil Contamination of air conditioning system. British Aerospace Systems, Hatfield
31. BAe (1990) Service information leaflet SIL 36/11: Bleed hogging trouble shooting procedures. British Aerospace Systems, Hatfield
32. BAe (1991) Service information leaflet SIL 21/30: Cabin and flight deck malodors trouble shooting procedures. British Aerospace Systems, Hatfield
33. BAe (2001) All operator message (AOM) Ref 00/030V: Smoke and fumes. British Aerospace Systems, Hatfield
34. Rolls Royce (1983) Notice to operators: RB211-22B, RB 211-524. Cabin odour—known causes. Rolls Royce
35. BAe (1990) BAe 146 Manufacturer's Operations Manual: Emergency and Abnormal Procedures Check List/Smoke or Fire Protection. British Aerospace Systems, Hatfield
36. BAe (2000) BAe 146 manufacturer's operations manual: notice to aircrew, operational notice: no OP 16 and 43 (issue 1). British Aerospace Systems, Hatfield
37. Honeywell (2001) Engine manual ALF502R—Temporary revision no 72-888: revised oil leakage inspection procedures. Honeywell (Allied Signal) Phoenix
38. NJS (2001) Operations manual: notice to BAe 146 pilots 37/97: BAe 146/Avro RJ—air conditioning contamination. National Jet Systems, Adelaide
39. Honeywell (2002) ALF/LF 502/507 engineering activity update. Honeywell (Allied Signal) Phoenix
40. Allied Signal (2003 service bulletin SB ALF/LF 72-1082. Allied Signal Aerospace, Phoenix
41. SAE (1981) Aerospace information report AIR 1539, 30/1/81, environmental control system contamination: sources of vaporous contamination. Society of Automotive Engineers, Warrendale, PA
42. Montgomery MR, Wier GT, Zieve FJ, Anders MW (1977) Human intoxication following inhalation exposure to synthetic jet lubricating oil. Clin Toxicol 11:423-426
43. (2000) Ansett Australia submission and evidence by Ansett Australia to the Australian Senate Inquiry into Air Safety (1999-2000) BAe 146 Cabin Air Quality. Parliament of Australia, Canberra
44. Mobil (1983) Correspondence: Mobil Jet Oil II. Mobil Oil Corporation, Environmental Affairs and Toxicology Department, New York

45. O'Brien K (2002) BAe 146 aircraft: Q398. Hansard, Australian Parliament House, Canberra
46. CASA spokesperson (2003) News in science—Possible solution to toxic aircraft cabin air. Australian Broadcasting Commission Radio News, Sydney
47. Borger H (2003) High on the flight deck. Occupational health and safety magazine. CCH, Sydney
48. CASA (2000) Civil aviation regulation 2. Civil Aviation Safety Authority of Australia, Canberra
49. CASA (2000) Major defect reporting manual. Civil Aviation Safety Authority of Australia, Canberra
50. CASA (2001) Defect reports, Civil Aviation Advisory Publication 51-1(1). Civil Aviation Safety Authority of Australia, Canberra
51. Vamvakinou M (2004) Air safety—Cabin air quality: Q3011. Hansard, Australian Parliament House
52. ATSB (1999) Occurrence brief 199702276, BAe 146, VH NJF, Fumes in cabin from oil leak in APU, 10 July 1997. Australian Transport Safety Bureau, Canberra, http://www.atsb.gov.au/aviation/occurs/occurs_detail.cfm?ID=256
53. ATSB (2000) Occurrence brief 200002431, BAe 146, VH NJL, Fumes in cabin from oil leak in APU, 30 April 2000. Australian Transport Safety Bureau, Canberra, http://www.atsb.gov.au/aviation/occurs/occurs_detail.cfm?ID=93
54. ATSB (2003) Occurrence brief 200203243, BAe 146, VH NJR, Fumes in cabin from oil leak in APU, 22 July 2002. Australian Transport Safety Bureau, Canberra, http://www.atsb.gov.au/aviation/occurs/occurs_detail.cfm?ID=472
55. ATSB (2003) Occurrence brief 200204912, BAe 146, VH NJL, Fumes in cabin from oil leak in APU, 20 October, 2002. Australian Transport Safety Bureau, Canberra, http://www.atsb.gov.au/aviation/occurs/occurs_detail.cfm?ID=517
56. ATSB (2003) Occurrence brief 200205865, BAe 146, VH NJX, Fumes in cabin from oil leak in APU, 2 December, 2002. Australian Transport Safety Bureau, Canberra, http://www.atsb.gov.au/aviation/occurs/occurs_detail.cfm?ID=542
57. NJS submission and evidence by National Jet Systems, Adelaide, to the Australian Senate Inquiry into Air Safety (1999-2000) BAe 146 Cabin Air Quality. Parliament of Australia, Canberra
58. Pavlinovich N (2003) Witness statement to Australian Industrial Relations Commission. U2002/6475 N. Industrial Relations Commission, Perth
59. CAA mandatory occurrence reporting database. UK Civil Aviation Authority, London
60. ASHRAE (1999) standard 161—Air quality within commercial aircraft—Committee review draft
61. AFAP submission and evidence by Australian Federation of Air Pilots, Melbourne, to the Australian Senate Inquiry into Air Safety (1999-2000) BAe 146 Cabin Air Quality. Parliament of Australia, Canberra
62. Senate of Australia (2000) Air safety and cabin air quality in the BAe 146 aircraft. Senate Rural and Regional Affairs and Transport References Committee. Parliament of Australia. Final report, Canberra
63. Michaelis S (2003) A survey of health symptoms in BALPA Boeing 757 pilots. *J Occup Health Saf Aust N Z* 19:253-261
64. BALPA (2004) B757 and BAe 146 fume event reports (2004). Unpublished data. British Airline Pilots Association, London
65. Singh B (2004) In flight smoke and fumes. Australia Aviation Safety Spotlight 0304
66. ICAO (2001) Aircraft accident and incident investigation, 9th edn, annex 13. International Civil Aviation Organisation, Paris

67. ATSB air navigation act 1920. Australian Transport Safety Bureau, Canberra
68. ATSB Editorial: New air safety accident or incident report. Australian Transport Safety Bureau, Canberra, http://www.atsb.gov.au/aviation/editorial/forms_article.cfm
69. UK CAA (2002) flight operations department communication (FODCOM) 21/2002: smoke/fume occurrences. UK Civil Aviation Authority, London