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Aircraft Air Quality Malfunction Incidents: Causation, Regulatory, Reporting and Rates

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Abstract The issue of aircraft air contamination due to oils and hydraulic fluids leaking into the aircraft air supply is a known problem in the aviation industry. There are a range of regulations that are in place to ensure all cases of fume contamination are reported and therefore investigated. However, there is strong evidence that the reporting system to regulatory agencies is not working and, consequently, under-reporting occurs and the fume events taking place are considerably higher than the aviation industry admits. There are a variety of reasons for this including commercial pressures, fatalism about long-standing and apparently insurmountable engineering problems, operational procedures that focus on keeping aircraft flying and a culture to minimise health and safety risks. These have significant health and safety implications for crew and passengers.

Keywords Aircraft air contamination · Fumes · Reporting · FAR/JAR 25.831 · ASR · MOR

Abbreviations

APU	Auxiliary Power Unit
BAe	British Aerospace
BALPA	British Airline Pilot's Association
CAA	Civil Aviation Authority of the United Kingdom
CASA	Civil Aviation Safety Authority of Australia
FAR	Federal Aviation Regulations
JAR	Joint Aviation Requirements
MOR	Mandatory Occurrence Reporting

1 Introduction

There is no question that air safety is an important issue. Unlike many other types of transportation accidents, the loss of a passenger airplane in flight is a catastrophe. There are a range of factors that can lead to airplane accidents, including problems of language [1], problems of communication [2], problems with technology [3], and problems with attitudes to safety [4, 5]. One major aircraft manufacturer recently stated that its definition of aircraft safety was based upon the aircraft not having had a fatality due to a technical problem [22].

As commercial imperatives drive any business, the need to keep aircraft flying is critical and malfunctions in aircraft could be seen as a threat to business activities. A system needs to be developed that identifies such malfunctions, assesses their significance and efficiently resolves the problems they create. One such problem, discussed below, deals with malfunctions in the engine or hydraulic system that lead to flight deck and passenger cabin air quality problems.

Studies indicate [7, 8] that it is common that all modes of transport have ventilation rates less than current ASHRAE 62 guidelines for commercial buildings [9]. For example, a Canadian study of one aircraft type and airline found that 25 of 33 commercial flights did not satisfy the ASHRAE air ventilation criteria of 15 ft^3 per occupant and that 18 of 33 flights had less than 10 ft^3 per occupant [10]. This finding, of itself, does not imply poor air quality. However, it suggests that initiatives to reduce air quality should be resisted and indicates that opportunities to improve air quality should be encouraged.

The cabin of an airplane is a specialised working environment and should be considered as such. Recommendations for pressurisation of airplane cabins (to an equivalent of 8000 ft) were established in the 1960s using healthy male volunteers. This is sufficient to lower the partial pressure of oxygen (from 159 mm Hg at sea level to 118 mm Hg), that is, a level that may have an impact on physiological function (itself dependent on blood O_2 saturation) of some individuals and an impact on physiological function is more likely where individuals are undertaking effort.

The oils and hydraulics used in airplane engines are toxic, and specific ingredients of oils are irritating, sensitising and neurotoxic [11]. When oil or hydraulic fluids leak, they can contaminate the air supplied from the engines or APU and may be in the form of unchanged oil/fluid, degraded oil/fluid from long use in the engine, combusted oil/fluid or pyrolised oil/fluid. A leak may be in the form of gases, vapours, mists and particulate matter. If leak incidents occur and the oil/fluid is ingested into the air being used for the cabin (bleed air) and passed to the flight deck and passenger cabin, exposed staff and passengers may be exposed to contaminants that can affect their health and safety and they do not have access to appropriate information that can advise them as to hazard, risk or control of exposure. Where leak incidents are known to be 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. Therefore, the use of risk acceptability criteria for chemical exposures, such as exposure standards or threshold limit values (TLVs), to conclude that exposures are acceptable is inapplicable in certain situations in the aviation industry [11, 12]. Such standards should not be applied at altitude, or in other situations where the possibility of escape to fresh air is lacking. Acceptability criteria for chemical exposures at altitude must consider the interaction of reduced oxygen, skin exposure to mists, and interactions with other contaminant exposures.

Contaminants may be well below current recommended safety standards, yet generate complaints due to the synergistic effect. Some standards are outdated having not incorporated more recent medical and scientific evidence. Additionally, extenuating factors onboard aircraft including humidity and cabin pressure have not been studied to the extent that new standards can be proposed incorporating these factors or interactions between them [13, 14].

There is currently no agreement amongst aviation toxicologists on whether the threshold limit values (TLVs) or NASA spacecraft maximum allowable concentrations for airborne contaminants (SMACS) are the most appropriate toxicological standard [15]. Symptoms of immediate nature and reported by exposed staff in single or small numbers of repetitive incidents are consistent with the development of irritation and discomfort. Symptoms of a short term nature (that is, continuing symptoms for up to 6 months) reported by some exposed staff following escalating numbers of leak incidents are consistent with the development of initially temporary but eventually irreversible health problems in a number of body systems. Additionally, symptoms of a long term nature (that is, sustained symptoms for at least 6 months) reported by some exposed staff following an intense or significant number of low level leak incidents are consistent with the development of an irreversible discrete occupational health condition, termed aerotoxic syndrome [14, 16]. 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 air quality provisions of the Federal Aviation Regulations (FAR), most notably FAR 25.831a/b [17].

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 their health.

Information provided by oil manufacturers to airplane manufacturers understates the toxicity of their oil products [11]. This has been accepted uncritically by aircraft manufacturers and airline operators and is used by them in a manner that misleadingly understates risk. Additionally, all studies that have been carried out to measure atmospheric contamination in airplanes from leak events are sufficiently flawed on methodological inadequacies as to render their conclusions invalid [11].

Evidence is available that suggests that there are a substantial number of leak incidents on airplanes, especially on certain models of aircraft. 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 and of those leak incidents that are reported to regulatory authorities, not all are added to relevant databases. Additionally, only a very small number of leak incidents are investigated fully and are available for review; however, most of these investigations have been found to be inadequate.

2
Engine Lubricating Oil and Hydraulic System Malfunctions

2.1
Sources of the Problem

The aviation industry itself acknowledges that air quality exposure events are primarily due to oil leaking into the air supply. For example, company memos, industry and government submissions to previous Government Inquiries, and other documentation indicate:

- Society of Automotive Engineers (SAE) aerospace information report [18]
  "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."
- Mobil Oil (manufacturer of Mobil Jet Oil II) [19]
  "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."
- Allied Signal (manufacturer of airplane auxiliary power units [APU]) [20]
  "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."

- British Aerospace (BAe, manufacturer of airplanes)
  "Every engine leaks oil from its seals and bearings." [22].
  "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 APU" [73].
  "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" [22].
  BAe Service information leaflet 21-45, Troubleshooting - operator experience of oil contamination of the engine/APU bleed air [74]
- Ansett Australia (former airline)
  "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"[23].
  "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" [24].
- Civil Aviation Safety Authority of Australia (CASA)
  "All engines and APUs leak oil and suffer fumes as a feature of the design of air conditioning systems using bleed air" [25].
- Civil Aviation Authority of the United Kingdom (CAA)
  "Although the exact cause of crew incapacitation is not yet 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" [26].
  "Although the immediate investigations were not able to find a definitive cause of the symptoms experienced, circumstantial evidence suggested potential contamination of cabin air by abnormal concentrations of noxious gases or vapours" [27].
  "Evidence from these incidents indicated that contamination of the ventilation systems by engine oil fumes was the most likely cause" [28].

There is a paradox in that all parties acknowledge that a problem exists, but then deny that it is a serious matter. Many deny that it is an air safety issue, rather an occupational health and safety (OHS) general health or comfort issue [22–25, 29].

Dozens of in-cabin leak/smoke events are documented annually, often correlated to aircraft fluid leak events. However, leak incidents are much more frequent, correlated to less obvious aircraft fluid leaks and residual contamination that are seen by many as a normal part of flying [11, 30].

2.2 Regulatory Requirements

National aviation safety regulations such as the FARs and JARs cover areas of airplane performance, and include ventilation airworthiness requirements that require a sufficient amount of uncontaminated air to be supplied so that the crew can operate without undue discomfort or fatigue and so that the cabin be free of harmful or hazardous levels of gases or vapours [17].

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.

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.

The aviation industry refers to ozone, carbon monoxide and carbon dioxide when considering contaminants in terms of the airworthiness requirement, [31] and has until recently ignored all other contaminants.

2.3 Reporting Requirements

There is a spectrum of defects and malfunctions in an airplane engine ranging from the trivial to the serious, to the catastrophic. As trivial malfunctions can escalate into serious events, it is necessary to ensure that all types of malfunctions are identified, investigated and rectified.

FAR/JAR regulations impose strict guidelines on how aircraft defects are defined, must be reported, investigated and dealt with. Of necessity, these are based upon those airworthiness standards taken from the FARs and JARs that cover aircraft design and operation.

The regulations are clear on maintenance and reporting. For instance in the UK, the aircraft commander must report all technical defects in the aircraft technical log [32]. Reportable occurrences are incidents or defects which, if not corrected, would endanger the aircraft, its occupants or any other persons and are to be made to the aviation regulator under the Mandatory Occurrence Reporting (MOR) scheme. These must be filed by the Captain as an MOR with the CAA within 96 h so as to advise of hazardous or potentially hazardous incidents and defects [33, 34]. A few examples include fire; explosion; smoke or toxic or noxious fumes that resulted in the use of emergency equipment or procedures; incapacitation of any member of the flight crew or incapacitation of any member of the cabin crew that rendered them unable to perform essential emergency duties; leakage of hydraulic fluids, fuel or oil that resulted in possible hazardous contamination of the aircraft structure, systems or equipment or risk to occupants.

In Australia, reports required include reports of "major defects" and "defects". 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" [37], or "smoke, toxic or noxious fumes inside the aircraft" [36]. All defects must be reported in the aircraft technical log by the pilot by the termination of the flight [37], with a defect being seen as an "imperfection that impairs the structure, composition or function of an object or system" [36]. Reports on major defects such as oil contamination must be made and investigated in a variety of ways and reported to CASA within 2 days [37, 38] as well as the "accumulation or circulation of toxic or noxious gases in the crew compartment or passenger cabin" [39]. Air safety reports must be made to the Australian Transport Safety Bureau (ATSB) within 72 h for any occurrence that could affect the safety of the operation of the aircraft [40].

2.4 Evidence of Reporting of Defects

The reporting systems documented under the International Civil Aviation Organization (ICAO) protocols and legislated by national aviation safety regulations are established so that information arising from incident events passes from the aircraft operator to the regulator and manufacturer, such that modifications can be made where necessary and so that the information is shared by all parties. These must be adhered to for the information to be utilised effectively.

However, there are many different types of mandatory and non-mandatory report formats available. Some of the mandatory reports include: defect reports in the aircraft technical log, defects and major defects sent to the aviation regulator, and air safety incident reports. Some of the non-mandatory reports include: airline and crew internal reports/information; reports sent between the manufacturer, regulator and operator; confidential reports to the regulators or bureau of air safety; union reports; crew surveys; medical/legal reports; passenger reports and so on.

In fact, 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.

Other possible sources of data that can be used to suggest that incidents are occurring include manufacturer's service bulletins (SB), service information leaflets (SIL) and the airworthiness directives (AD) that are issued to deal with problems identified in the operation of aircraft.

Despite the fact that there are over 240 advisory service bulletins, service information leaflets and other manufacturer and operator communications for two aircraft types relating to the specific issue of oil leaks and fume contamination from 1984–2003 [41], the CAA and CASA have only issued three ADs in support of fumes (see paper by Best and Michaelis in this volume). An AD is issued by a regulator to compel the aircraft operator to comply with manufacturer's service bulletins in the case where a safety threat exists or could exist. Until recently, oil fumes in Australia were not seen by CASA as a major defect and were not forwarded to CASA, despite the regulations necessitating this [42, 43].

Table 1 shows a small fraction of the known incidents, which are based on reported and accessible information. This information must be looked at whilst bearing in mind the scale of under-reporting, which is examined later. The information available is clearly greatly dependent on the source. It can be seen that there are a substantial number of reports on particular types of aircraft. Some of the more significant ones are:

- One BAe 146 operator reported oil/fumes every 66 flights in 1992, reducing to every 131 flights in 1999; and 775 mandatory aircraft technical log reports in two and a half years [23].
- The British Airline Pilots Association (BALPA) survey of B757 pilots showed that 106 pilots reported in excess of 1667 fume events, mostly thought to be associated with oil contamination of the air supply [44].
- FAA service difficulty reports search (SDRS) shows 8268 cases of smell, fume, odour, gas, toxic fume, or toxic gas from 1986 to 2000 [45].
- There were 760 reports of contamination at one US airline on the MD80 aircraft from 1989 –1998 [45].
- For BAe 146, 791 optional odour occurrences were reported [46].
- 146 BAe aircraft operators made 439 reports from 1985 to 2000, including 212 from one operator over 3 years [47].

Despite even the very limited numbers in Table 1 that are high, particularly in the case of the Ansett Australia Airlines BAe 146, the aviation industry regulators report that fumes/oil contamination is a rare event.

Ansett Australia Airlines claimed that fume events are a "very very rare occurrence" [23] but at the same time encouraged its crews to report odour occurrence events (yet this was acknowledged as still widely under-reported [46]). The crews who worked on a fleet of 13–15 aircraft, operating an average number of sectors per day, reported one fume-related event every 66 flights in 1992, reducing to one every 131 flights in 1999 [23]. The odour/fume reports were primarily associated with leaking oil [23]. Therefore, this "very, very rare occurrence" could amount to a fume/oil related defect report every day or two.

In the UK, the CAA state that smoke, gas or leak incidents occur once every 22 265 flights (128 events from 1989 to 1999) [48, 49] and the CAA say they

Table 1 Rates of aircraft smoke/fume/oil and other fluid contamination

Type of report and country	Dates	Aircraft	Number	Comment	Source
BALPA - UK	2001	B757	1667+	1667+ reports of smoke or fumes mostly thought to be from oil in air conditioning system	[44]
UK CAA MOR*	1988–Jan 2004	B 757	104+	"Smoke and or fumes" – oil/smoke/fumes/de-icing/hydraulic fluid • 16 reports 1988–1998 • 88 reports 1999–January 2004	[51]
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	[51]
Other UK data	1998–2004	B757	47	Reports sent via email or airline reports (not on CAA data base)	[56]
Other UK data	2002–2004	BAe 146	23	Airline reports not on CAA data base	[56]
CAA - UK	1989–1999	5 Jet types	128	Smoke/gas fumes (non-mandatory) • 1 event every 22 265 flights • B757 (21), BAe 146 (17)	[48, 49]
AAIB - UK	2000–2002	BAe 146/B757	19	Smoke/fumes incidents, • B757 –10 • BAe 146 – 9+	[50]
BAE - UK	1985–2000	BAe 146	439	• 36 operators reported 227 cases of contaminated air -1985–2000 • 1 operator reported 212 cases of tainted cabin air 1996–1999	[47]
Aircraft defect reports - Australia	1991–1999	BAe 146	775	Mandatory reports in aircraft technical log. Number of reports • 1992 – 418 reports = 1 every 66 flights • 1997 – 189 • 1999 (6 months)–168 reports = 1 every 131 flights	[23]

* Some MOR reports not available for review and others referred to as defects only with no MOR

Table 1 (continued)

Type of report and country	Dates	Aircraft	Number	Comment	Source
Odour occurrence reports -Australia	1991–2000	BAe 146	791	Optional BAe 146 odour occurrence reports (predominantly Mobil jet oil II leaking into air supply)	[46]
CASA - Australia	1996–2002	BAe 146	22	Examples of oil seal bearing defects, fumes and crew impairment	[54]
ATSB - Australia	1991–2002	BAe 146	32	Oil/hydraulic fume - smoke or odour incidents	[55]
FAA - US	1986–2000	Various	8268	SDRS - Smell, fume, odour, gas, toxic fume, or toxic gas	[45]
AFA - US	1989–1998	MD80	760	900 reports at 1 airline (73% on MD80)	[45]
FAA - US	1989–1999	Various	167	Accidents and Incidents Data Systems (AIDS) • 23 (14%) air quality events 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)	[53]
FAA - US	1992–2000	Various	4360	Fumes generated by engine/APU clearly present • hazard level 0–2** • events with no definitive cause not included • less than 1 in 1,000 events were serious threat to flight safety or immediate serious physical harm	[77]
NTSB - US	1990–2000	Jet transport	5	Smoke/fumes	[52]
TSB - Sweden	1999	BAe 146	1	All crew members "temporarily affected by probably polluted cabin air"	[47]

* Some MOR reports not available for review and others referred to as defects only with no MOR

** hazard level 0 – consequences with 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.

have 189 MOR reports on two aircraft types (162 from 1996 to 2004) [51]. The UK Air Accidents Investigation Bureau (AAIB) had 19 reports of smoke/fume incidents from 2000 to 2002 on the BAe 146 and B757 [50].

In the US, the FAA state that there is one air quality incident every 3 590 000 departures (23 related to toxic contamination in ventilation systems) [53] and the FAA AIDS database has 60 cases of ventilation toxic contaminant events from 1978 to 1999 [53]. However later data [77] reports one fume event per 10,000 flights or less.

In Australia, CASA states there have been 22 events in 6 years [54] (despite evidence showing defect reports occurring up to every 131 flights on the BAe 146 fleet [23], i.e. almost every day). Fume events are also thought to be to be 50% greater than reported [46], with others suggesting a 90% under-reporting rate with fumes seen as a normal part of flight [30]. The Australian Bureau of Air Safety (ATSB) had 32 BAe 146 incident reports of oil or hydraulic fumes/smoke or odour incidents from 1991 to 2002 [55].

Some data that is known to have been reported fails for various reasons to actually be present on regulator databases. BALPA has had 47 Boeing 757 reports sent direct from crews via email or submitted to airlines which did not get entered into the UK CAA database, as well as 22 BAe 146 airline reports (all from one airline) which are not on the UK CAA database [56].

Another example of how many regulator databases lack accuracy in relation to fume events is that there are 775 mandatory Australian BAe 146 aircraft log reports [23] and 791 optional "BAe 146 odour occurrence reports" [46] which were mostly reported to Ansett Australia, yet only 32 were received by the Australian Transport Safety Bureau (ATSB) [55], and a very small number appear on the Australian CASA database [54].

Use of information from within one source is often inconsistent and can vary greatly. An example is the UK CAA data which lists 56 fume events from 1996–2003, 66 cases where crew and passengers suffered symptoms of discomfort, while the MOR database shows 162 reports during this period. This does not even take into account the incomplete database and under-reporting factors [51, 56, 57].

The differing databases and lack of real understanding of the scale of the problem led one BAe 146 operator to state that events were increasing over a period of time, while the regulator stated that there was a decrease in reports [58, 59].

Other examples of how defects and fumes are reported include:

- BAe complaint of difficulty report: report 27803.BAe 146 reported by B Rogers of BAe regarding Dan Air: "Can Hatfield (British Aerospace) provide a definitive statement on the medical implications of fumes/smells in the cabin ... Dan Air cabin crew have complained of headaches and nausea ... Here we have a reported case of fumes and nausea and despite a 2 year wait we still have no statement on health and safety. Can you please hasten an answer at this point" (February 1991) [60].

- Ansett Australia BAe 146 odour occurrence report: "All three flight attendants had tightness in chest, sore throats, headaches, slurred speech from purser during P/A" (May 1995) [46].
- UK ASR – B757: "Toxic fumes in flight deck. Aircraft had two previous flights with oil fumes in flight deck reported. Suggests air conditioning ducting needs to be cleaned before further flight. Captain felt giddy and ill, while First Officer, ground staff and cabin crew all reported headaches and feeling unwell" (1998). This ASR was not passed to the UK CAA, despite the MOR box being ticked requiring the report to be forwarded to UK CAA [56].
- UK CAA MOR 200007913 – B757: "Fumes on flight deck and in cabin. Recurring fault considered to be residual engine oil contamination in the bleed ducts. Reporter confirms that similar incident had been reported on previous sector and that the aircraft has a history of oil leaks ... although there were no written reports as such. After take-off thrust was set, a strong smell likened to "burning rotten socks" was apparent on flight deck ... during climb, smell was still evident on flight deck – each pilot in turn breathed 100% oxygen because they both felt light-headed ... on shut down both pilots still felt light-headed and also shaky" (October 2000 [51]).
- CASA major defect database – BAe 146: "No 1 engine No 9 bearing seal leaking. Suspect fumes entering cabin and causing crew problems" (August 2001 [54]).

Indeed, the difference between statistics due to under-reporting, varying data on internal databases, reporting to operators, and "official" reporting to regulators allows all parties to use flawed data to perpetuate well-entrenched positions with important health and safety trends ignored.

2.5 Under-Reporting

The Australian Senate inquiry into the BAe 146 cabin air quality recognised that under-reporting was a major problem [61]. The 2001 BALPA Boeing 757 survey reported 1667 fume/smoke incidents [44], while the UK CAA database shows only 104 Boeing 757 reports over the same period [51]. These figures highlight the problem of relying on regulator databases for accuracy concerning the scale of the problem whilst under-reporting continues to occur.

The reasons for under-reporting are complex. There is a long-standing culture existing in some airlines of crews not reporting fumes or reporting leak incidents verbally [62] and some crews may be discouraged from writing reports in the aircraft log [63]. It must also be remembered that fumes and their 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 [22, 23, 25].

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 [44]. Crews may be fearful of reporting fumes due to awareness that some crews have been harassed, stood down and or terminated after reporting fumes [58, 64] and that others have lost their medical licences [65, 66]. Others 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 [44, 46, 51, 61, 68]. 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 [44]. Additionally leak incidents that do not effect all crew members equally are not viewed by some as an aircraft defect [67].

Oil seals are not as efficient in certain stages of flight and therefore the problem may be seen as being intermittent and part of normal operations [73]. Failure of some airline engineers to rectify leak problems or to comply with ventilation regulations such as FAR/JAR 25.831 does not encourage crews to report fumes, especially when leak incidents are often reported to be rectified at "company convenience" [68], "not safety of flight", "for information only", "no fault found", "report further" or similar [30, 51, 69].

Leak incidents may occur over numerous sectors and are often ongoing over days, sometimes months [51, 58] with residual contamination being an important problem on some aircraft [11, 69], which also fails to generate reports. Additionally there is an accepted practice in the industry of only reporting non-vital defects at the end of the day or duty.

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 [29, 51, 69].

3 Conclusions

It can be seen that there are engine oil and hydraulic fluid leaks occurring on aircraft due to reasons which include the design issue that some engine seals are not as efficient in transient operations, residual contamination events and more major contamination events due to part or full system malfunctions. This, combined with the fact that fume events have been under- recognized and under-reported and seen as more of a nuisance, raises a number of significant concerns.

It is clear that these fume events and the medical effects experienced by crews and passengers, occur a lot more frequently than the industry and regulators are prepared to publicly accept. In some cases the regulator actually denies that pilots could conceivably fail to report all fume events, yet this is factually known to occur [44, 56, 62, 70].

Even if collated fully, the documentation will not collect together the majority of incidents actually occurring because of the under-reporting problem, but it could at least show important trends. Despite fume events relating to oil contamination being dismissed by the CAA as being of "no risk to health or safety" [71] the lack of accurate data is of concern due to the health and safety ramifications from the medical effects of crew breathing contaminated air. Crew symptoms of feeling unwell or irritation are not seen as a regulator responsibility unless classified as partial impairment or greater such that the safety of flight and landing is affected [57, 70]. Regulatory agencies and manufacturers usually claim that the issue is one of OHS importance and not one of flight safety [25], despite acknowledging that this is outside their field of expertise [22, 25]. Conversely, the OHS authorities claim the problem is not within their responsibility as it is an aviation regulator problem [67]. Airlines, not surprisingly, usually claim it is neither a health nor safety issue.

While fumes have generally been dismissed as a "non-event" [72], one manufacturer has acknowledged that fumes were previously seen as a "nuisance" rather than as a potential threat to flight safety [73, 74]. Aviation safety notes that use of oxygen is a "serious incident" [75], but crews generally do not using oxygen even though advised that it is required when fume events are suspected [26].

The same source of data may give conflicting information [77] and additionally the exclusion of fume events without definitive links to the engine or APU may reduce the true level of incidents and hence the degree of the problem. The selective interpretation of fume events deemed to be of concern may also downplay the scale of the problem.

Fume and smoke events that are listed at the time of the incident to have no 'reported' effects on crew or passengers have led many to downgrade the full range of significant health & safety implications of exposure to contaminated air from leaking oil & hydraulic fluids. Events not reported to cause immidiate serious threat to flight safety are not being given the attention they deserve, particularly given the known problems of under and incomplete reporting of many fume events.

The true extent of the problem remains largely unknown. For the full scale of the problem to be better understood the regulators need to enforce regulations that require leak incidents to be reported, and the reports that are made need to be forwarded to the regulators as required by the legislation.

In general, the regulations surrounding contaminated air defects on aircraft are not being followed. While low numbers of major incident leak reports 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 the rigor that only incorrect dogma can produce.

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" [12].

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