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Rulemaking Directorate
European Aviation Safety Agency
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Germany

Submission by Susan Michaelis (Capt): To accompany all sections of A-NPA comments made by EASA CRT, 8/1/10

RE: A-NPA No. 2009-10 'Cabin air quality onboard large aeroplanes'

Dear Sir / Madam:

I am a former Australian commercial pilot and have researched the aircraft contaminated air issue for 13 years since 1997, since having to cease flying and having my medical removed by CASA after repeated contaminated air events. Since this time I have published numerous papers, made presentation internationally, am the head researcher for the Global Cabin Air Quality Executive (GCAQE) and am the author of the only collated source of data on this issue: Michaelis S. (2007) Aviation Contaminated Air Reference Manual. ISBN 9780955567209. I have recently submitted a PhD thesis on this issue, specifically related to contaminated bleed air systems.

While I am pleased that EASA is at last taking some interest in the contaminated air issue, the content of the A-NPA is of concern as it shows an appreciable lack of understanding of the currently available data on the subject and a significant industry bias. Given that contaminated air is an airworthiness issue, this of course is a major area of responsibility for EASA.

Acute and chronic symptoms caused by exposure to pyrolyzed engine oil on aircraft have been recognized since the 1950s,[1] With one exception,[2] airlines, aircraft/component manufacturers, aviation regulators, and government sponsored committees have made little effort to systematically investigate these smoke/fume events and the associated reports of ill health,[3,4,5,6,7,8,9] instead describing them as 'anecdotal' and similar. Therefore the flight safety issues have been overlooked with contaminated air events deemed a nuisance rather than a flight safety hazard.

I feel I more than qualified to offer my expertise on this issue based on my extensive research covering the flight safety aspects as well as the short and long-term health implications. My 844 page fully sourced reference manual and recently submitted thesis in addition to my global awareness of the available data and thinking supports this of course. I would be more than happy to brief EASA at a suitable time in the near future on my latest research and PhD findings at a suitable time.

I have sent EASA by courier a copy of my reference manual listed above along with selected other material and trust this will be carefully reviewed. The reference manual is seen as Ground breaking and seminal work by the RAAF in Australia. Many other published papers can be found at: http://www.aopis.org/ScientificReports.html

It is not possible to cover the whole issue of aircraft contaminated air in one document here. It has taken me 13 years of solid research to amass this knowledge. However while I support the GCAQE submission of course and share it's concerns, I will briefly address the 4 questions EASA has posed in the A-NPA.

A. WHAT CONTAMINANTS ARE RELEASED TO THE CABIN AND FLIGHT DECK, AND IN WHICH QUANTITY?

The vast majority of air quality monitoring has been carried out on aircraft in normal conditions of flight without any reported fume events.[10,11,12,13,14,15,16,17,18,19,20] These aircraft sampling projects and many others were not designed to capture air supply contamination events.[10,21]

A few aircraft sampling studies with very small sample sizes were intended to investigate bleed air contamination on commercial [8, 22,23,24, 25] and military[26,27] aircraft. Reported levels of airborne contaminants were stated to be below the occupational exposure limits for the limited number of chemicals for which limits have been published. Data subsequently revealed a leading manufacturer cabin air study had found TCP above it's manufacturing plant allowable limits, however this information was withheld from the published reports. [8,28,29,30,31]

However, occupational exposure standards do not apply to aviation.[8,28,32,33,34,35] Also, even if occupational exposure limits did apply to a confined space at altitude that transports members of the general public, few of the chemicals identified in oil-contaminated cabin air[10] have occupational exposure limits to which to compare. Further, passengers are not 'healthy workers' and are not covered by exposure standards, chemicals are present as mixtures and not in isolation, all aircraft occupants are exposed in a reduced pressure environment, and crewmembers can be assigned to work shifts that are 14 hours or longer, all factors that must be accounted for.[36] The ACGIH does not recommend exposure standards to be applied above 5000 feet.[37]

While engine oils are made up of a number of substances, it is the degraded or pyrolyzed substances from the heated lubricant that is of prime importance in a reduced pressure environment. However, the composition of the oil additive tricresylphosphate (TCP) in a given engine oil is an important factor when attempting to define the toxicity of a given oil. However the isomeric blends of TCP in commercial aviation engine oils are proprietary. As background, there are ten chemical variations ('isomers') of tricresylphosphates (TCPs), some or all of which are added to most commercial aviation engine oils.[38] This is relevant because the toxicity of the various TCP isomers is not uniform, and the tri-ortho isomer is neither the only, nor the most, toxic. The chemical constituents of some pyrolyzed oils have been defined,[39,40,41,42,43] but a complete analysis of the TCP isomers has not been possible because chemical standards have not been available for all isomers. Recent military studies have reconfirmed that virtually all of the ortho (TCP) isomers are in the mono form, which are the most toxic and that the various isomers are identifiable despite the standard remaining confidential.[44]

Exxon-Mobil has confirmed that oil fume contamination of the aircraft air supply system does not constitute 'normal' usage,[45] yet the MSDSs only cover normal usage. However Mobil has asserted that it's published and internal risk assessments indicate such exposures are safe and the only recognized risks are gastrointestinal effects and OPIDN, organophosphate Induced delayed Neurotoxicity, yet such effects could not occur in the aircraft cabin.[45,46,47,48] However such assertions are inappropriate for a variety of reasons including:

1. The majority of symptoms reported by crew and passengers exposed to oil fumes indicate central nervous system (CNS) damage (e.g. headache, difficulty concentrating, memory problems, slowed mental processing and response time, balance problems, depression, and visual irregularities).[2,23,49,50,51,52,53,54,55,56,57, 58,59,60] The fact that there are no published animal data on CNS toxicity of inhalation exposure to TCPs (whether the six ortho isomers or the remaining four meta/para isomers that dominate TCPs in engine oils) does not mean that TCPs do not damage the CNS. The more subtle but significant symptoms of CNS damage reported by exposed crewmembers are not possible to assess directly in animal studies, and post-mortem brain analyses of structures or regions involved in cognition or emotion have not been funded. A neurotoxic effect of exposure to meta/para TCP isomers has been suggested because the results of experimental studies cannot be explained by the presence of the ortho-isomers alone.[61] Using neurotoxic esterase enzyme activity as an endpoint, an oil manufacturer identified low, but consistent, neurotoxicity in formulations derived almost entirely of meta/para isomers that it had expected to be inactive.[62] 1964 US Navy studies found it 'highly suggestive' that components other than ortho isomer groups of the triaryl phosphates have significant toxicity or are capable of synergizing or potentiating other triaryl phosphates.[63]

2. Even if the ortho isomer content in aviation engine oils is lower than some decades ago, an association with reported peripheral nervous system damage cannot be ruled out for the following reasons: there is no defined 'safe' exposure level for inhaling mixed TCP isomers; there are defined genetic, endocrine, and environmental factors known to influence an individual's ability to metabolize organophosphates;[64,65,66] there is a dearth of exposure data from the aircraft cabin/flight deck; and there is no information on the health impact of chronic exposure to low-levels of pyrolyzed engine oils. One study assessed symptoms of peripheral neuropathy in hens orally dosed with engine oils containing TCPs. The authors reported an 'unexpected high neurotoxic potency of the aviation engine oil containing 3% TCPs and less than 0.02% of TOCP.'[67] These TCP contents are comparable to aviation oil products used industry-wide today. Administering heated oils to test animals via inhalation (instead of unheated oils orally) would be expected to increase the observed neurotoxic impact[61,68] and would better reflect exposures on commercial aircraft.
3. The oil MSDSs do not indicate there is no hazard and prior to 2004 the MJO II and 254 MSDS warnings and oil can labels reported: *'Overexposure to TCP by… prolonged or repeated breathing of oil mist… may produce nervous system disorders including gastrointestinal disturbances, numbness, muscular cramps, weakness, and paralysis….'*

TCP, the synthetic lubricant additive has been found in aircraft on numerous occasions including; RAAF (1988/2005), Honeywell (1997,2000) Lee, Qantas, CAA (2004), Van Netten (2005/2006), NIOH, Muir (2008), GCAQE (2009), TNO (2009), OHRCA (2009) and WDR (2009[),8,,22,24,25,26,27,28,29,30,69,70,71,72,73,74,75,76,77,78.] In summary TCP has been recorded in at least 15 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). 75 out of 88 (85%) swab samples for TCP have positively identified TCP. Therefore exposure to TCP in the passenger cabin is occurring and the isomers can be accurately identified to correspond with the unique TCP isomer formulation used in jet engine oils.[44,79] TCP has also been found in crew member's blood following contaminated air events.

Even if the inhalation toxicity of all 10 TCP isomers were addressed, TCPs are not the only candidates in pyrolyzed engine oil that could be responsible for the symptoms reported by exposed crewmembers and should not be considered in isolation.[61] Hundreds of chemicals have been identified in the supply air of commercial aircraft contaminated with engine oil [8,10,24,25,28,29,30,40,43] and others, like the neurotoxin trimethylolpropane phosphate (TMPP), have been proposed as a potential exposure risk when ingredients in the engine base stock react with TCPs at elevated temperatures.[80] TMPP formation has been recorded at temperatures as low as 250ºC,[81] which is within the range of an operating aircraft engine which can range from 300 to 650 °C in the high stage compressor section to between 50 and 300 °C in the intermediate (low stage) compressor.[82,83] A US Navy research team reported that such high levels of TMPP were generated when Exxon 2380 (now marketed as BP2380) engine oil was heated that it recommended that the product be banned on US naval vessels.[84] The research team attributed the high levels of TMPP to the trimethylolpropane phosphate (TMP) base stock reacting with the TCP additives. Most aviation engine oils contain pentaerythritol ester (PE) base stocks which are not associated with TMPP formation. Some engine oils may contain a combination of TMP and PE base stocks. Despite the recognized potential for the formation of high levels of TMPP, BP2380 is widely used on the commercial fleet globally. The study also recommended that that all polyol ester based synthetic oils in the U.S. Navy inventory should be tested for the production of TMPP and that *'research should be initiated for overall toxicity of combined, combustion byproducts rather than for any individual combustion product present.'*[84]

Trying to identify a single contaminant that is responsible for the diverse neurological and respiratory symptoms reported by exposed aircraft occupants, and to define a 'safe' level for all occupants is an impossible task for the reasons stated above. The use of the traditional dose response rationale ignores the following factors: the potential for either an additive or a synergistic response to a mixture of chemicals;[34,85,86] the impact of exposure to chemicals (especially carbon monoxide) in a reduced pressure environment;[87] the potential health impact of repeated exposures and chronic low-level exposures;[57,88,89] and the other factors referenced here that influence individual susceptibility to organophosphates and other chemicals such as pyrethroid insecticides.

Some parties consider that if aviation regulations are met then the aircraft supply air will be clean and safe. EASA requires that aircraft manufacturers design air supply systems to provide 'enough fresh air… to enable crewmembers to perform their duties without undue discomfort or fatigue' (CS 25.831(a)) and that the 'crew and passenger compartment air be free from harmful or hazardous concentrations of gases or vapours' (CS 25.831(b)). The US Federal Aviation Administration (FAA) has published similar design standards (14 CFR 25.831(a) and (b)). The terms 'undue discomfort or fatigue' is subjective and even 'harmful or hazardous' may be open to interpretation. As such the term harmful relating to adverse effects ought to be the determining factor or the use of correct application of the hazardous substance regulations. Still, there are many documented examples of pilot impairment caused by oil fumes (described in the next section) that would meet even the most conservative interpretation of these terms. In those events then, at a minimum, these aviation regulations were not met. In 2002, the FAA acknowledged that '[no] present airplane design fulfills 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.'[90] Still, to date, no aviation regulator requires airlines to install and operate either bleed air monitoring or bleed air cleaning systems, despite the many recommendations on the subject.[2,6,9,26,91,92,93,94]. At present, neither EASA nor the FAA requires air quality monitoring so there is no guarantee that the airworthiness regulations (FAR/CS 25.831 a/b are being met at all times.

The FAA requires that maintenance work restore the aircraft to its original (i.e. design) condition (14 CFR 43.13 (b) and (c)). This concept of 'continuing airworthiness' is recognized globally.[95] However once gain there is ample evidence to support that continuing airworthiness related to contaminated air is not being met at all times. Additionally the application of MELs is not appropriate for contaminated bleed air supply as such incidents are in fact airworthiness / safety issues (as per FAR/CS 25.831) for which MELs must not be applied.[35,96]

B. WHAT IS THE EFFECT ON FLIGHT SAFETY?

More than 30 years ago, a published case study of a healthy 34-year old flight navigator exposed to oil fumes inflight described 'disturbance in [his] mental and neuromuscular function' and noted that 'by the time the plane could be landed, he had difficulty standing.'[58] The 1977 investigation and subsequent report found oil fume reports were not uncommon and that the toxicity of the synthetic jet oils was 'definitely warranted.' A review of 89 incidents of smoke/fumes in the flight decks on military aircraft from 1970-80 described 'incapacitating central nervous system dysfunction and mucous membrane irritation' and concluded that 'smoke/fumes in the cockpit is not a rare event and is a clear threat to flying safety because of acute toxic effects.'[57]

From 1979-81, 10 turboprop aircraft, all equipped with the same Garrett engine, crashed, leaving 38 fatalities. Oil residues were identified in the engines from one of the aircraft that had been retrieved from the bottom of a lake. The US National Transportation Safety Board (NTSB) initiated an investigation into whether a cracked engine oil seal might allow 'toxic or anaesthetic byproducts of the oil to enter the aircraft's environmental system.'[97] The NTSB noted that, if identified, such exposures could compromise flight safety and could be a risk on all bleed air aircraft. The NTSB partnered with the aircraft engine and oil manufacturers, introducing a known quantity of oil into the compressor section of a Garrett engine and measuring the bleed air contamination downstream. In most of the trials, liquid contaminants were removed with a glass wool filter prior to the sampling port, even though the bleed air on the crashed aircraft had not been filtered. The researchers concluded, based on the gaseous contaminants that they measured in the filtered air, that the 'hypothesis concerning subtle pilot incapacitation due to engine oil contamination of the bleed air supply… is completely without validity.' However, a companion study published by the FAA acknowledged the possibility that 'with an unfiltered [bleed air] line, a significant toxicity could be associated with breathing the oil mist.'[98]

In 1999, the Australian Transport Safety Bureau (ATSB) issued a report of an oil fume event inflight where the pilot 'suffered from a loss of situational awareness.'[99] Upon approach, 'his control inputs had become jerky and he began suffering vertigo.' The incident was attributed to oil fumes in the flight deck air (based on mechanical records) but the pilot in command had reported that no smoke or fumes were present so he did not use the smoke removal checklist and none of the three pilots donned their oxygen masks.

In 2000, an Australian Senate inquiry into oil contaminated bleed air summarized a series of pilot-reported incapacitation events. Upon exposure to oil fumes, pilots reported 'difficulty in concentrating on the operation of the aircraft' and 'a feeling like drunkenness [resulting in] difficulty lining up the aircraft for landing.'[2]

Since 2000, the UK Civil Aviation Authority (CAA) has issued four bulletins to airlines that warn of the risk of pilot incapacitation caused by exposure to toxic oil fumes inflight and recommend procedures to protect against pilot incapacitation.[100,101,102,103] The agency notes that 'reducing occurrences of oil contamination will also reduce the risk of flight crew incapacitation.'[101]

In 2001, the CAA initiated a research program into aircraft air quality in response to the increase in reported smoke/fume events, including a small number of events where 'flight crew have been incapacitated to a greater or lesser degree.'[101] The published research report concludes that 'engine oil fumes were the most likely cause' for the acute symptoms and found no evidence of other causal factors.[5]

In 2001, Swedish air safety investigators published a report regarding a smoke/fume event on a commercial aircraft during which the captain was 'having difficulty with physiological motor response, simultaneity, and in focusing.'[23] The contaminated flight deck air was attributed to an engine oil leak. The investigative report stated that subsequent air sampling by the aircraft engine manufacturer did not identify the cause of either pilot's symptoms, but the air sampling data released years later cited the presence of a wide range of contaminants, including tricresylphosphates and triphenylphosphate, specific to oil contamination.[24,25]

In 2004, the FAA issued an Airworthiness Directive (AD) requiring BAe146 operators to prevent the accumulation of oil residue in the air supply system ductwork.[104] The FAA stated that these procedures were 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.' The FAA had issued this AD in response to a service bulletin published by the aircraft manufacturer which stated that oil leaks and odors 'must be regarded as a potential threat to flight safety.'[105] Prior to this time the manufacturer acknowledged that oil fumes had been seen as a nuisance.[105] Other regulators had issued similar ADs regarding oil fumes on the BAe 146 prior to the FAA action, all indicating oil fumes are regarded as a flight safety risk.[106,107,108,109,110,111,112,113]

Also in 2004, the UK Air Accidents Investigation Branch (AAIB) reported an incident of oil fumes in the airliner flight deck in which the 'first officer's condition began to decline to an extent that he had difficulty in concentrating… The commander also felt light-headed and had difficulty in judging height and in the ensuing approach and landing.'[114] The report concluded that there was 'circumstantial evidence' that the flight crew had been affected by exposure to oil that had contaminated the APU.

In 2006, the Swiss Aircraft Accident Investigation Bureau published its investigation into a report of oil fumes in the flight deck.[115] The report concluded that 'the serious incident is attributable to the fact that on approach… the cockpit filled with fumes which caused a toxic effect, leading to a limited capability of acting of the copilot. These fumes were caused by an oil leak…'

In 2007, the AAIB reported another incident of oil fumes in the flight deck.[94] The report identified 153 other smoke/fume incidents and concluded that 40 of them had involved 'adverse physiological effects on one or both pilots, in some cases severe.' The report recommended that EASA and the FAA require flight deck detection and warning systems for oil smoke/mist. The same call for detection systems was repeated in 2009 by the AAIB.[93]

These are just a few examples of industry acknowledgement that oil fumes pose a threat to flight safety. There is a vast amount of supporting evidence showing impairment is occuring in flight not on an infrequent basis. Recent research has found that of 1050 contaminated air events in the UK, 32% recorded crew impairment in flight, while 20% showed at least 1 pilot was impaired in flight with 9% of events showing both pilots impaired in flight ranging from mild to incapacitation.[116] A host of other flight safety issues were demonstrated including the low use of oxygen by pilots during contaminated air events.[116,117] In fact oxygen was used by 1 pilot during 4% of contaminated air events and both pilots in 12 % of such events.[116]

3) CAN IT INDUCE A HEALTH CONCERN?

The acute health risks outlined in the response to the previous question describes crewmembers' reports of acute symptoms inflight, with a focus on neurological symptoms which are the primary complaint. Exposure to synthetic jet oils have been acknowledged within the aviation industry to cause a variety of short term symptoms also highlighted on a typical jet oil MSDS.69[,118,119,120,121,122,123,] The NTSB recognized in 1983 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.'*[124] A UK Government report found that acute effects due to contaminated air exposures were 'plausible',[3] while the Executive Director of the Aerospace Medical Association reports that exposure to VOCs used in aircraft operations can cause skin rashes, pulmonary and CNS symptoms ranging from mild to severe.[33] SAE stated in 1981 review of bleed air and synthetic oils that at *'temperatures above 320C this oil breaks down into irritating and toxic compounds'*.[125] Many other industry bodies have acknowledged that exposure to synthetic jet engine oils is hazardous including Rolls-Royce.[126],[127] Selected other examples include :

- BAe Systems: ***'****With the weight of human evidence and suffering, which is quite clear, there must be something there'*… *'There is absolutely no doubt in our mind that there is a general health issue here'*[128]
- CASA:*'Mobil Jet Oil II- Known to be harmful'*[129]
- UK Government:*'The inhalation of mist (containing tricresylphosphate) which can be produced by high pressure systems, or direct contact with the skin, would be hazardous.'*[130]

- FAA: *'JAR-E includes a unique hazard, `toxic bleed air''*[131]
- German Government: *'Does the German Government believe that inhaling of heated engine oil fumes is harmless for the health of crew and passengers?'.* Answer *'No'.*[132]
- German Regulator: *'Oil leakage… and oil residues… may lead to harmful contamination of the cabin air and cause intoxication of the flight crew.'* [133]

As to chronic effects, the primary symptoms reported and documented by exposed crew and passengers indicate central nervous system (CNS) damage (e.g. chronic headaches, difficulty concentrating, memory problems, slowed mental processing and response time, balance problems, depression, and visual irregularities).[2, ,23,49,50,51,52,53,55,56,59,60,]77[,123] Chronic neurotoxicity and autonomic nervous system damage have also been reported.[61,134,135]

A proportion of the crews and passengers exposed to oil fumes have reported symptoms consistent with peripheral nervous system damage (e.g. paraesthesias, tremor, abnormal gait). These symptoms are consistent with exposure to the six 'ortho' isomers of TCP (of which the tri-ortho isomer, TOCP, is one) which have been affirmed as being highly toxic to the peripheral nerves in animal studies, both by a German toxicologist in the late 1950s[136] and the worlds' leading aviation engine oil manufacturer, Mobil Oil (now Exxon-Mobil), forty years later.[62] While TOCP has received almost all the research attention over the decades, it has been long known that the mono- and di-ortho isomers of TCP are five to 10 times more toxic than TOCP, TOCP has been (incorrectly) assumed to be a suitable surrogate.[137]

In addition to the neurological symptoms described above, damage to the upper airways and lungs have been reported and documented,[49,50,51,52,53,54,60,77,123,138,139,140,141] causing symptoms including chest tightness, difficulty taking a full breath, wheezing, coughing, and shortness of breath. As well, some crewmembers report symptoms such as skin rash/sensitization, gastrointestinal upset, muscle weakness, and joint pain,[49,51,52,55, ,60,]77[,123] and psychiatric symptoms such as depression.[,49,]77

Other conditions have been reported by crew and their physicians that are reported in published literature including alzheimers, Parkinsons, Grade 4 GBM, MND and MS.123. [142,143,144] Chronic effects have been recognized elsewhere.[32,123,145,146]

My recent research of BAe 146 pilots and B757 pilots has highlighted significant short and long-term health effects that show a strong temporal association with contaminated air. While the research is a part of my thesis and will be available fro review later this year, previously published preliminary data shows that of approximately 300 pilots surveyed to date, in excess of 85% acknowledged they were aware of the contaminated air; 65% reported some degree of adverse symptoms (short, medium or long-term) and an oil fumes exposure history; around 30% showed medium to long-term adverse effects of a similar pattern; with in excess of 10% of those surveyed medically retired, retired then suffering ill health of a similar nature with all having a long history of exposure to oil fumes. I have since identified a smaller subset with well known chronic disorders inn association with a strong history of oil fume exposure. [123,147] This research is supported by previous research I have undertaken.[52,55]

NYCO, a French producer of synthetic jet engine oils and a significant supplier of such oils for the military market, has revised their MSDS for TURBONYCOIL 600. The new MSDS incorporates risk phrases Xn 62.F3 (harmful: Possible risk of impaired fertility.) and Xn 63.G3 (harmful: Possible risk of harm to the unborn child). The changes were based upon NYCO sponsored research undertaken at the University of Washington investigating selected neurotoxicity of various organophosphate additives including TCP and TIPP. Both additives were found to produce 'a non-negligible potential' of neurotoxicity, while the newly discovered NYCO proposed alternative OP additive is claimed to a significant improvement in term of neurotoxictity and this matter should be fully investigated and supported by EASA to further reduce the health and safety risks associated with inhalation and dermal exposure to pyrolised/heated synthetic jet engine oils.

4) WHAT IS THE FREQUENCY OF THIS KIND OF EVENT?

It has been widely recognized that the incidence of smoke/fume events varies according to aircraft type, engine type, and maintenance practices,[2,3,9,148] but no current aircraft type or airline is immune.[116,149] The Boeing 787 aircraft scheduled to enter commercial service in 2010 should not be subject to bleed air contamination with oil because the supply air is processed in electrically-generated compressors independent of the engines.

In the absence of a reliable reporting system or air quality monitoring requirements, it is difficult to estimate the frequency of smoke/fume events on commercial aircraft. Still, there are sufficient data to conclude that smoke/fume events are not rare. This has been clearly acknowledged within the aviation industry as shown below and in my research.[116]

Based on data from three United Kingdom (UK) airlines, a government sponsored committee estimated that pilots experience oil smoke/fume events on 1% of flights and that maintenance identifies the smoke/fume source on 0.05% of flights.[3] One explanation for the discrepancy is that engineering faults can be difficult and time-consuming to identify. Mechanics routinely release aircraft with some version of 'no fault found, return to service,' only to sometimes divert with smoke/fumes on the subsequent flight.[116,117,149]

A review of publicly available smoke/fume event data for the US fleet over an 18-month period identified a daily average of 0.86 documented smoke/fume events involving oil or hydraulic fluid, considered an underestimate for reasons provided.[83] The primary data source for these events was Service Difficulty Reports (SDR) that the FAA requires airlines to submit for reports of all smoke/fume events inflight and any such ground-based events that may compromise flight safety. Frequency estimates from three Canadian airlines range from 0.09 to 3.88 events per 1,000 flight cycles depending on aircraft type and airline.[9] Australian operators reported oil fume events as often as once in every 66 flights or 1.5% of flights, while the manufacturer stated the following clearly identifying a design issue that is part of the way oils seals operate:

- *'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.'*[150]

However, the true frequency of oil fume events may be much higher than what is documented. Aviation regulators in many countries have issued reporting requirements for smoke/fume events, but there is evidence that compliance is lacking. Also, the regulators need not share the data publicly.

For example, in Europe, aviation authorities in member states must require pilots, airlines, manufacturers, and other parties with knowledge of an occurrence involving 'smoke or toxic or noxious fumes' to report to their respective aviation authority.[151] However, one survey of commercial airline pilots in the UK reported that less than 4% of suspected oil fume events were reported at all.[55] Only a small proportion of events that even get reported to the airlines are actually reported to the authorities, as required.[116,117]

In the US, the FAA requires airlines to report 'each failure, malfunction, or defect concerning an aircraft component that causes accumulation or circulation of smoke, vapor, or toxic or noxious fumes in the crew compartment or passenger cabin during flight' (14 CFR 121.703(a)(5) and 12 CFR 125.415). Airlines must also report ground-based events if flight safety is or may be endangered (14 CFR 121.703(c) and 14 CFR 135.415(c)). However, the FAA recently reported that numerous airlines may not have reported smoke/fume events as required,[153,154] and there is no published evidence of improved reporting since then.

In Australia, the Civil Aviation Safety Authority (CASA) requires each pilot in command to enter all defects of which they are aware on the aircraft maintenance release (technical log) at the termination of each flight, and the airline must conduct a 'suitable' investigation (CAR 248, 50, 51). Since 1992, CASA has classified 'smoke, toxic or noxious fumes inside the aircraft' as a major defect,[155] (previously CAO 100.8) which means that maintenance workers must report them to the airline, and the airline must report to CASA within two working days (CAR 51, 52A).

Crewmember underreporting of fume events has been noted both in military[32,57] and civil aviation. [2,]49[,116,117,153,154]**Error! Bookmark not defined.** The Australian Senate summary of its inquiry into air safety and cabin air quality specifically noted that pilots were reluctant to report fume events because doing so could jeopardize their flying license.[2] The Australian ATSB found that *'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.'*[156] The FAA has acknowledged the reluctance of pilots with ill health to voluntarily remove themselves from flying[157] and the US Air Force has noted the difficulty in acquiring complete and accurate medical information from pilots with a profession, hobby, or aircraft investment to protect.[158,159]

There is little doubt that the majority of fume reports are related to oil leakage. In 1990 Rolls-Royce stated that *'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.'*[162] The fact that fumes are predominantly associated with oil leakage ahs been acknowledged by regulators, airlines and manufacturers over the years along with the recognition that oil fumes are part of the design factor of using bleed air for the cabin air supply in addition to maintenance issues.[69, 150,164,165,166,167]

In addition to country or region-specific reasons for underreporting fume events, it is worth noting that all of the available smoke/fume data have been reported by crewmembers who were not trained to recognize or respond to oil or hydraulic fluid fume events, specifically.

CONCLUSION:

The issue of aircraft contaminated air has remained ongoing for several decades and has remained unaddressed and seen as outside the scope of the aviation regulator. Inhalation or exposure to oil fumes and other fluids in flight is a serious safety hazard and both short and long-term effects have been clearly identified, The aviation industry has to date not dealt with the issue appropriately at all and based on conduct documented, the term reprehensible conduct[168] (ICAO) is warranted and must be addressed.

RECCOMENDATIONS
Urgently required research includes:

- Synthetic jet engine oils and other fluids should be assessed for overall toxicity of combined pyrolysis 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 biomarkers and polyol ester based synthetic oils should be assessed for toxic by-products creation such as TMPP, inhalation toxicity of other TCP isomers (non ortho) and similar;
- Establish standards for all contaminants suitable for the cabin air environment and the heated mixture of contaminants, rather than individual ground based standards;
- Better designed engine and APU oil seals and bleed air systems that do not allow oil to leak;
- 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;
- Research should be undertaken into the health effects associated with contaminated bleed air using case control studies and expertise free of industry/Government alliances.

Urgently required actions include:

- TCP should not be used as a substance in synthetic oils. 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;
- 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;
- 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 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;
- EASA should adopt the ICAO resolution that protects passenger and crew health.[173]
- All future aircraft should be designed in a 'bleed free' manner as is the case with the Boeing 787 Dreamliner.

Please do let me know if I can be of further assistance in helping EASA to identify the true extent of this issue and means to address it. I am currently based in the UK and would be pleased to brief EASA in further detail at a suitable time.

Sincerely,

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