Is it time to act?

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Exposure to neurotoxic aircraft cabin air contaminants is viewed as both a health and a safety problem. Key issues relevant to the lack of action to resolve the problem are highlighted.

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The all too common call, from within many corners of the aerospace industry and associated bodies, that more research is required to determine whether exposure to oil lubricants via aircraft cabin air supply occurs, is an outdated and facile argument.

There are all too many reasons given as to why the extent of the problem is still open for discussion. A few of the more common (but flawed) arguments include:

(1) fume events are rare as they are infrequently reported;
(2) levels found in studies undertaken are below government-set exposure standards;
(3) the level of tri-*ortho*-cresyl phosphate (T*o*CP) is too low to cause the recognized neurotoxic condition OPIDN;
(4) too few people report adverse health effects;
(5) aircraft air quality meets the required standard at certification.

Aircraft cabin contaminated air has been recognized since the 1950s and it is time such arguments were set aside in favour of a review of the evidence, which by now seems sufficient to admit a reasonably robust understanding. The points outlined in the following sections ought to be clearly understood by the supposedly safety-conscious aviation industry, yet this is not apparently the case.

1. ENGINEERING

The system of bleeding air from the engine compressors provides a mechanism for oil leakage as a function of system architecture [1]. Bearing chamber sealing using pressurized compressor air provides sealing against oil loss between bearings and rotating shafts. While it is commonly reported that seals fail infrequently, various factors allow lower levels of oil to leak into the air supply as a function of normal flight.

Commonly used labyrinth seals utilize a design clearance, while carbon or mechanical seals require face lubrication, with both types allowing some oil leakage [2]. While seals are designed to limit leakage, there is no such thing as a seal that does not leak [2]. Sealing clearance is critical in labyrinth seals, which are designed to keep oil leakage to a minimum by pressurizing the bearing sump with compressor bleed air utilizing a controlled leakage of air to maintain higher pressure on the outside of the chamber. However, the pressurized seals are responsive to variations in engine power changes, enabling oil to pass the seal under certain operating conditions. Seal wear, particularly with carbon seals, provides a further mechanism for oil leakage.

Oil leakage past certain seals is a recognized and accepted and escape of air/oil mist or aerosol via the system "breathers" are two of the three main accepted ways in which oil is lost, made good by regular topping up of the system [3] (The third way is spillage during servicing).

2. FREQUENCY

There have been many suggestions that contaminated air events are very rare (based upon reported events), but this fails to take into account the engineering mechanisms allowing oil to leak. Instead, such suggestions rely upon the well documented failure of the reporting system, [1, 4–9] despite clear regulations requiring all suspected fume events to be reported. The design and operation of the bleed air system readily explains the frequency of lower-level exposure to oil fumes; the human nose should not have to be used as the primary indicator of such exposures (not all of which are associated with odour).

3. SUBSTANCES OF CONCERN: NOT JUST T*o*CP

It is often incorrectly reported that the only substances of concern are tricresyl phosphate and, specifically, the tri-*ortho* isomer T*o*CP. In actuality, exposure to oil fumes involves a variety of substances, including:

1) Oil base stock, which accounts for around 95% of the oil. US Air Force studies in 1954 identified the serious hazards associated with exposure to ultraheated ester base stock and its pyrolysis products [10];
2) Amine antioxidant substances such as N-phenyl-α-naphthylamine (PAN);
3) TCP: The commercial aviation lubricant blend of tricresyl phosphate (TCP) is a complex mixture of structurally related compounds not limited to just

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the 10 TCP isomers. The mixture includes substituted phenols and xylenols, reported to have virtually the same reactivity as TCP. One such example is trixylyl phosphate (TXP), used in the Supresta brand of TCP (SYN-O-ADD 8484), which is categorized under the hazardous substances globally harmonized system (GHS) as a Category1B, "toxic for reproduction" toxin.

4. ENZYME INHIBITION

Previous studies of possible biomarkers for TCP intoxication have tended to focus on the tri-*ortho* isomer of TCP (T*o*CP) and inhibition of one particular enzyme; recent studies have found a range of enzyme inhibitors [8]. The tri-*para* isomers of TCP, other triaryl phosphate isomers and the commercial aviation TCP formulation made by Chemtura (DURAD 125) were also found to inhibit a variety of enzymes [8], thereby effecting normal physiological processes.

5. RECOGNIZED HAZARDS ASSOCIATED WITH OIL SUBSTANCES

Under the United Nations-based GHS hazardous substances classification system, substances in the oils attract a range of hazard classifications of concern. Substances including TCP (all isomers), the *ortho* isomers of TCP, TXP and PAN clearly fall into the scope of either the mandatory harmonized system or the non-mandatory notified system including: "harmful by dermal exposure"; "may damage fertility or the unborn"; "eye and skin irritant with potential respiratory irritant properties"; "skin sensitization", "nervous system toxicant"; "very toxic by inhalation"; and "germ cell mutagenicity". Such hazards should not be ignored, nor their use in a complex heated mixture at altitude in an environment from which egress is generally not possible.

6. ADVERSE HEALTH EFFECTS

A clear pattern of short- and long-term adverse effects along with a chronic long-term pattern has been documented amongst aircrew [1, 4]. In many cases such effects are well confirmed elsewhere in the literature as being related to the substances in the oil and are further supported by the GHS hazard classifications. A recent study documented, respectively, 44% and 32% of pilots reporting short and long-term effects, which were consistent with exposure to oil fumes [4]. These effects included a range of respiratory, cardiovascular, neurological, neuropsychological, gastrointestinal, irritant and general symptoms reported in the immediate and short-term aftermath of putative exposures, with a clear development into the longer-term for some. 13% of the civillian pilot cohort experienced chronic ill health, such that they could no longer maintain pilot medical certification; they were either retired with a consistent pattern of long-term ill health or deceased for reasons considered to be connected to occupation. The rate of permanent ill health or loss of flying ability or both found in this study, ranged between 37% and 433% higher than the published rate of loss of pilot medical certification within the civil and military aviation industry for all reasons. Similar trends were seen internationally and across varying aircraft types, amongst both cabin crew and pilots and in some cases passengers.

7. REGULATIONS DO EXIST

There are a number of clearly interpretable regulations related to oil leakage, contaminated air and ventilation, however they are not being met [1, 4] and even if they were they are deemed inadequate [9].[1]

[1] These regulations relate to: (1) The reporting of suspected fume events in the aircraft technical log to the regulator and air safety bureau; (2) Airworthiness standards—ventilation: FAR/CS 25.831 a/b; (3) Design and safety analysis. As an example, EASA CS E 510 requires a safety analysis of the engine, including the compressor bleed systems. Major engine effects must be predicted to occur at a rate not in excess of that defined as "remote" ($< 10^{-5}$ per engine flight hour) and include "concentration of toxic products in the engine bleed air sufficient to degrade crew performance". Continuing airworthiness requirements necessitate that aircraft are maintained throughout their operating life in the condition to which they have been certified. Similar requirements apply to the APU. A major industry study reports that oil fume events occur in 1% of flights [11]. This rate of fume events (which does not take into account underreporting or the engineering aspects allowing oil to leak through seals) is far greater than the 10^{-5} (1 in 100,000) requirement and, therefore, clearly indicates the airworthiness standards are not being met; (4) Bleed air purity: adequacy or purity of the air supply must be ensured at certification when air is extracted from the compressor for the purpose of ventilation and pressurization. Original certification specifications did not allow oil to leak into the bleed air (MIL-E-5007D, 1973); (5) Warning systems: contaminated bleed air detection systems are required under FAR/ CS 1309c, which states "Information concerning unsafe system operating conditions must be provided to the crew to enable them to take appropriate action is required." The inhalation of engine oil and other contaminated air substances is an unsafe occurrence for a wide variety of reasons including: the oil safety data sheets, chemical database information, airworthiness standards and industry acceptance that this is an unsafe condition; (6) Occupational Health and Safety (OHS): There is a wide variety of OHS regulations applicable to workers that ought to be adhered to when dealing with hazardous substances.

8. CONCLUSIONS

A mechanism of exposure to engine oil in aircraft air supplies plainly exists. The substances in the oil at levels used in the oil are manifestly hazardous and human beings are at the delivery end, without effective filtration or other treatment of the air taken from the engine. It is no longer acceptable for the airline industry, and those supporting it, to suggest no action is required at present apart from further research to determine where there is a problem. An airline need not be concerned about being found guilty of "reprehensible conduct" if reasonable measures are taken to protect crew and passengers from injury from contaminated cabin air [12]. Industry-wide monitoring that provides early warning of potential bleed air contaminants may help potential defendants better prepare against negligence litigation [13]. Mitigating solutions to protect crew and passengers against contaminated air already exist. Barriers to their implementation may be expense or a cumbersome technology—in which case appropriate development work is called for—or simply inertia. It is time to move forward jointly and severally as an industry to ensure such measures are enacted with vigour and efficacity.

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