A critique of recent air sampling data collected on aircraft: how much exposure to neurotoxic fumes is acceptable?

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There is an ongoing debate within the aviation industry as to whether, and to what degree, it is acceptable to expose airline crews and passengers to neurotoxic oil fumes that contain, among other things, tricresyl phosphates (TCPs). Crew members around the world have reported neurological illness after reports of exposure to oil fumes, but exposure data are lacking. Instead, crews must largely rely on aircraft mechanical records to demonstrate that engine oil fumes contaminated their breathing air that is first compressed in either the aircraft engines or an auxiliary power unit ("bleed air"). A recent sampling study funded by the UK Department for Transport reported low levels of airborne TCPs on 23 of 100 passenger and cargo flights, involving four aircraft types. These findings are troubling, in part because none of the exposures triggered any of the airlines' reporting protocols. The reader is left to wonder what levels of TCPs might be associated with a "fume event" that does trigger reporting protocols. Equally troubling is the researchers' conclusion that the measured presence of airborne neurotoxins during these flights is acceptable, as is the lack of concern that the findings appear to have generated within aviation regulatory bodies, both within and beyond the UK. Given the absence of an agreed-upon "safe" concentration of engine oil fumes for aircraft occupants to inhale, regulatory bodies need to require airlines to either filter and monitor engine bleed air, or to operate aircraft with non-bleed systems that do not require occupants to breathe unfiltered engine air.

Keywords: aircraft, fumes, oil

1. INTRODUCTION

Globally, the debate on whether, and to what degree, it is acceptable to expose airline crews and passengers to neurotoxic oil fumes during routine commercial flights continues. Generally, on one side of the debate are crew member unions and passenger groups calling for airlines either to operate aircraft that do not use compressed and unfiltered engine air to ventilate the cabin and flight deck, or to filter and monitor such compressed engine air for oil-based contaminants before supplying it to passengers and crew. On the other side of the debate are airlines, aircraft and component manufacturers and aviation regulators, who claim that inhaling neurotoxic oil fumes does not explain reports of neurological illness amongst exposed aircraft occupants. As an example, the UK Civil Aviation Authority (CAA) endorses the engine oil manufacturers' position that an "average man can ingest seven metric tonnes of oil per day for 74 days without effect" [1].

One of the more recent exchanges involved the results of an aircraft cabin air sampling study funded by the UK Department for Transport and conducted by researchers at the Cranfield University Institute of Environment & Health (IEH). It is described in the next section.

2. DESCRIPTION OF THE SAMPLING STUDY

Researchers at Cranfield University's IEH collected airborne sampling data on a total of 100 passenger and cargo flights. The study was ostensibly responding to a UK House of Lords cabin air and health report [2]. The introductory section of Part 1 of the Cranfield report also cites some UK Committee on Toxicity (COT) recommendations to characterize concentrations of airborne pollutants associated with reported fume events during commercial flights [3]. However the COT review had recommended sampling on 10,000–15,000 flights to assess exposure to bleed air contaminants, not a mere 100.

The majority of sampled airborne contaminants were markers of exposure to pyrolysed engine oil and hydraulic fluid, both known to contaminate the outside air supply that is compressed in and drawn from either the aircraft engines or an auxiliary power unit ("bleed air") on commercial aircraft. Sampling included continuous measurements of total volatile organic compounds (TVOC), carbon monoxide and ultrafine particles, as well as five-minute average exposure measurements of some specific volatile (VOC) and semivolatile organic compounds (SVOCs), including tri-*ortho*-cresyl phosphate (TOCP), other tricresyl phosphates (TCPs) and tributylphosphate (TBP) [4, 5]. For the VOC and SVOC data (other than carbon monoxide), ten five-minute samples were collected

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according to a phase-of-flight schedule during each flight. The researchers collected an additional 30 five-minute samples, either when they noticed an unusual odour, or when the continuous sampling equipment indicated unusual elevations in the level of either TVOCs or particulates. The researchers collected these data on the flight deck during 100 flights on four aircraft types from September 2008 until February 2010. The four aircraft types were B757 (both cargo and passenger configurations), BAe146, A320 and A319. The samples were sent to one of two UK labs (BRE, AES), both with some experience in cabin air quality research, for analysis.

Despite some limitations (described below), this research study identified the presence of neurotoxic compounds in flight deck air on a significant proportion of passenger and cargo flights. The results themselves, as well as the surprising lack of concern that they have generated, are disquieting.

3. DISCUSSION

Historically, UK aviation regulators have acknowledged reports of acute and chronic ill health after exposure to bleed air contaminants on commercial aircraft [6–8, 1, 9–11]. However, the IEH study did not attempt to measure the prevalence of either short-term post-flight symptoms or chronic symptoms that may be associated with exposure to bleed air contaminants. Also, of the 552 crew members who completed a health survey towards the end of the 100 flights, the only reported symptom was a headache/slight headache, described by four people. This is consistent with the findings that the measured levels of carbon monoxide and other VOCs were relatively low (assuming that the nine carbon monoxide samples with measured levels at or above 9 ppm were in error, as the authors suggest). These results should not, however, be used to suggest that conditions on these pre-arranged flights are representative of flights during and after which crew members have reported either short-term or chronic symptoms post-flight.

An IEH researcher travelled on each sampled flight sector by prior arrangement with the airline. The majority of the samples were collected according to a predetermined phase-of-flight schedule. However, this may not capture all of the transient conditions (changes in engine power settings, for example) when engine oil is most likely to leak into the bleed air.

Semivolatile organic compounds, including TCPs, were sampled near floor level on the flight deck. Head height sampling would have better reflected concentrations in crew members' breathing zones. To illustrate the importance of sampling location, a 1978 study of ozone levels in the aircraft cabin reported that about 40% of the

ozone present at ceiling height in the economy class section had "disappeared" when compared to levels measured at a height of four feet above the floor, which had been selected to represent the breathing zone of seated occupants [12]. The authors concluded that the "disappeared" ozone had already contacted—and reacted with—surfaces. While the SVOCs in the IEH study are not as reactive as ozone, little is known about how they behave in air, so it does not make sense to sample at floor level when the goal is to characterize the concentrations in the breathing zone of aircraft occupants.

The authors limited their air monitoring to the flight deck, which may have underestimated exposure to bleed air contaminants in the passenger cabin on some of the non-cargo flights. Specifically, Part 1 of the report [4] references flights where cabin crew members reported odours, but the researchers did not notice any odours in the flight deck, so did not collect additional SVOC samples. Either a non-bleed odour source in the cabin or interindividual differences in sense of smell may explain these discrepancies. Also, on some aircraft types, bleed air contamination in the right-hand engine (for example) may contaminate the air supplied to the mid and aft cabin, but not the forward cabin and flight deck, assuming a twin-engine configuration with no mixing of bleed sources prior to supplying air to the flight deck. Further, oil-contaminated ventilation ducts can be an ongoing source of airborne contaminants, potentially having a localiszed effect on supply air quality.

It is not clear whether the "non-TOCP isomers of TCP" included all nine isomers, or only a subset. The authors cite the detection limit for four TCP isomers (other than TOCP) in Mobil Jet Oil II (ref. 4, Table F2), but it is not clear if they only characterized and reported on those four isomers (in addition to TOCP), potentially missing the remaining five isomers. The GC-MS retention times for eight of the ten TCP isomers have been characterized [13], with the exception of o-m-m and o-p-p. If the Cranfield authors only reported some of the non-TOCP isomers of TCP then they may underestimate actual TCP exposure, depending on the isomeric blend of TCPs in the engine oil(s) used by the participating airlines.

The detection limits for the five-minute SVOC samples appear to be as follows: TOCP = $0.04\ \mu g/m^3$; four other isomers of TCPs = $0.012\ \mu g/m^3$; TBP = $0.8\ \mu g/m^3$ (ref. 4, Table F2). These levels are relatively high, which is to be expected given that only 2.5 litres of air were drawn through the sorbent tube for each sample. Still, Table 1 in Part 2 of the report illustrates that the authors identified detectable airborne TOCP on 14 of the 100 flights, detectable airborne TCPs (multiple isomers) on 23 of the

100 flights, and detectable airborne TBPs on 73 of the 100 flights.

In Part 1 of the report, the authors reported the average exposure to TCPs, TOCP, TOCP+TCPs and TBP for each phase of flight sample-wise (ref. 4, Tables 6a–d). This method assumes that the five-minute sample represents the whole phase of flight (assuming the phase of flight is longer than five minutes). Given that some flights had nondetectable levels of these contaminants, this method of averaging dilutes any elevated five minute samples. Even relying on a five minute average sample may dilute shorter-term peak exposures. The authors also averaged the 10 (or so) five-minute samples collected during each flight, and called it a "flight-long average", although the average concentrations during the unmonitored minutes of flight are unknown. The authors then averaged the "flight-long average" exposures for each contaminant across 100 flights (ref. 4, Table 5). This unorthodox method of presenting averaged data (averaged during five-minute sampling interval, averaged within a flight with questionable assumptions, and averaged across 100 flights) and percentiles, significantly dilutes individual measurements and downplays the potential health impact of exposure.

Commercial aircraft are not fitted with sensor equipment for airborne contaminants in the bleed air supply. Instead, occupants must rely on their sense of smell. Regarding detectability of exposure to oil and hydraulic fluid fumes, 60 of 552 crew members on these flights who completed a post-flight survey described some kind of odour on 38 of the 100 flights. Almost half (26 of 60) of these odours were described as "oily." The health impact of repeated exposure to low levels of oil fumes that contain neurotoxic compounds such as TCPs is unknown. The fact that only four of 552 people reported a headache on these 100 flights does not mean that there is no chronic health impact.

Despite the odour reports and the significant proportion of flights with detectable levels of airborne neurotoxins (all described above), there were no fume events during these 100 flights that triggered any airline reporting protocols (ref. 4, p. 7), even though the CAA requires the aircraft captain to report technical defects in the aircraft log at the end of each flight, and maintenance is required to inspect and either rectify or defer maintenance, according to specific rules [14, 15]. In addition, cabin crew members are required to report defects that may affect either safe operations or airworthiness to the flight deck crew [15]. An oily odour suggests either a leak or spill of engine oil into the bleed air ventilation supply system, and should not be deemed "normal operation". It appears that the captains on the sampled flights should have reported the oily odours, assuming that they were either present on the flight deck or had been reported to the flight deck crew.

In addition to logging suspected defects or failures in the aircraft technical log, UK crew members must report to the CAA "any incident which endangers, or if left uncorrected, would endanger, an aircraft, its occupants, or any other person" [16, 17]. Reportable occurrences specifically include "toxic/noxious fumes" and "leakage of hydraulic fluids, fuel, oil or other fluids which resulted in ... possible hazardous contamination of aircraft structure, systems, or equipment, or risk to occupants," all under the agency's Mandatory Occurrence Reporting (MOR) scheme, which, in turn, is based on the EU mandatory reporting directive [16]. However, crew members are left to decide for themselves whether a given concentration of oil fumes, for example, is toxic or noxious, or at what point the exposure may possibly be hazardous or pose a risk to occupants. Airline crews presently receive no education or training on how to recognize and respond to oil fumes. In its MOR guidance materials, the CAA implies that crews should deem acceptable the "normal day-to-day flow of defects/incidents," and appears to discourage reporting all but the most hazardous events [17]. The agency refers "overenthusiastic" reporters to "the normal organizational systems and procedures," which, presumably, include the aircraft technical log (described above) and internal airline incident reports that are kept private. The Cranfield researchers' conclusion that the airborne concentrations of neurotoxic substances on these flights were acceptable appears to reflect the safety culture of both the CAA [17] and the European Aviation Safety Agency [18].

The authors of the IEH report averaged the exposure data across and between flights (as described above), and seem to suggest that the levels are innocuous because they are within occupational exposure limits (OELs), where applicable. The only possible exception that they note is a five-minute average TOCP concentration of 0.02 mg/m^3 on one flight (ref. 4, p. 36). The suggestion that compliance with available OELs means that the conditions are acceptable is problematic for many reasons. First, there are no OELs for nine of the ten TCP isomers, five of which have been characterized as more toxic than TOCP, which is the only isomer with an OEL. Also, most of the pyrolysed oil and hydraulic fluid constituents were not monitored. But even if there were OELs for every contaminant present, OELs (although rarely updated, so often out of date) are intended for the majority of ground-based workers exposed for eight hours each day with 16 hours of recovery time; they are not intended for application in a reduced-pressure, confined space with

limited (if any) egress that includes a cross-section of the general public, for workers with flight safety/security duties during work shifts that can routinely last 12 hours or longer.

Also on the subject of exposure limits, the authors continually cite the EN 4618 standard, which was developed by the very industry it is intended to regulate. It has not been endorsed by a regulatory authority and was passed with considerable controversy, because some crew member unions and standardization bodies in the EU raised significant concerns with it and its sister standard prEN 4666, which have not yet been addressed. As such, it is not an appropriate benchmark for either safety or health.

Finally, it is not valid to compare five-minute (and even flight-long) aircraft sampling data to residential sampling data that were reported as an average and collected over a period of weeks. Unlike a home, an aircraft is a reduced pressure, confined and sealed environment. Pilots are expected to be alert and oriented to perform complex tasks, potentially under emergency conditions. Subtle changes in reaction time, attention span, and cognition caused by exposure to airborne toxins are likely to have more significant ramifications for airline pilots inflight than for people in residential settings. Likewise, cabin crew members are responsible for passenger health, safety and security so they should not risk exposure to airborne toxins that could alter their cognitive function or physical wellbeing in flight.

4. CONCLUSIONS

In 1955, an engineer with North American Aviation Inc. (now part of Boeing) recommended that, in light of the risk of exposure to oil fumes in flight, airlines should either operate non-bleed ventilation systems or filter the engine bleed air before supplying it to passengers and crew (Reddall, 1955). Fifty-six years later, aircraft manufacturers almost exclusively design and build systems that bleed ventilation air off engines that sometimes leak toxic oil, without filters or monitors upstream of the cabin and flight deck. Furthermore, commercial airlines continue to operate those aircraft with neither adequate preventive maintenance nor crew training on how to recognize and respond to oil fumes. The only commercial aircraft that does not supply unfiltered engine bleed air to passengers and crew is the Boeing 787, which entered passenger service this year.

One would have expected the authors of the IEH report to express concern that TOCP, TCPs and TBPs are airborne and detectable on the flight deck, given that neither crew members nor passengers should be exposed to any of these chemicals. In turn, Cranfield's aircraft sampling

data should have motivated regulatory bodies to require manufacturers and airlines to better prevent exposure to neurotoxic fumes during commercial flights. For now, the debate and any resolution appear, sadly, far from over.

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