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Use of Exposure Standards in Aviation

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ABBREVIATIONS

TCP	Tricresyl phosphate
OEL	Occupational exposure limit
TLV	Threshold limit value

ABSTRACT
The use of occupational exposure limits and threshold limit values in the aircraft environment is examined in relation to aircraft air supplies contaminated by engine oils, hydraulic and other fluids used in aircraft.

INTRODUCTION

In recent years there have been an increasing number of aircraft air quality studies either in the cabin air or the bleed air supply. These have very often suggested that the levels are better than in homes, offices, schools and are below regulated standards and occupational exposure limits. Several examples follow:

- UK Department of Transport study (2011): *"There was no evidence for target pollutants occurring in the cabin air at levels exceeding available health and safety standards and guidelines."*[1]
- ACER/ASHRAE (2012) *"The air quality and environmental conditions in the passenger cabin of commercial airplanes are comparable or better than conditions reported for offices, schools and residences, with a few exceptions."*[2]
- EASA (2017): *"The results show that the cabin/cockpit air quality is similar or better than what is observed in normal indoor environments (offices, schools, kinder gardens or dwellings). No occupational exposure limits and guidelines were exceeded."*[3,4]
- KLM/TNO (2017): *"Exposure to [tricresyl phosphate] TCP was evaluated against internal exposure limits. It was concluded that the calculated exposure was below these limits, with one exception."*[5]
- Industry study (2018): *"The maximum concentrations of TCP detected in this study were less than 2 ug/m3 for the reported single events and less than 0.05 ug/m3 for non-event flights, which is far below the occupational exposure limit (OEL) of 100 ug/m3 and the threshold limit value (TLV) of 20 ug/m3, which was most recently derived for the more toxic ToCP"* by the ACGIH.[6]

The application of the various occupational exposure limit (OEL) thresholds and comparison to other environments however requires careful review. To put the use of exposure limits in context, US based threshold limit values (TLVs) *"have been, and still are, the most influential OELs in the world,"*[7] and are commonly used internationally as a source for national OEL recommendations.[8]

Use of threshold limit values (TLVs)

The American Conference of Governmental Industrial Hygienists,[9] a non-governmental scientific association, propose guidelines known as threshold limit values (TLVs) for use by industrial hygienists in making decisions regarding safe levels of exposure to various hazards found in the workplace.

The ACGIH are not a standards setting body, however they provide a number of guidelines on how the proposed thresholds limit values should be used.[9] These include that TLVs are: not regulatory or consensus standards; should only be used by people trained in industrial hygiene; one of multiple factors to be considered; health based limits that nearly all workers

may be repeatedly exposed to without adverse effects; not fine lines between safe and dangerous; not an indicator of toxicity, disease, adverse effects; some individuals may experience discomfort or more serious adverse effects at or below the threshold limit. Reasons for increased individual susceptibility may include age, gender, ethnicity, genetic factors, lifestyle choices, medications and pre-existing medical conditions. Some individuals (e.g. sensitized workers) may become more responsive to one or more chemical substances following previous exposures and altered effects may occur during different periods of fetal development and throughout an individual's reproductive lifetime. Changes in susceptibility may occur at different work intensity when there is a differing cardiopulmonary demand.

TLVs are related to airborne concentrations and are not to be used for extended periods or for non-workers, or for proving or disproving a disease in an individual. Air sampling may be insufficient to quantify skin exposure levels.

Sampling results obtained under unusual conditions (normal is 25C, 760 torr barometric pressure at MSL) cannot easily be compared to published TLVs, and extreme care should be exercised if workers are exposed to very high or low ambient pressures. Unusual work schedules greater than eight hours per day require particular care when applying TLVs. TLVs are only available for limited substances and not all are up to date.

Importantly TLVs apply to single substances, with special consideration required to be given to the application of TLVs in assessing health hazards that may be associated with a mixture of two or more substances. The TLV additive formula is not applicable to complex mixtures with many components such as thermal decomposition products. No physiological effects of oxygen deficiency are expected at oxygen partial pressures > 132 torr or below 5000 feet as shown in Figure 1.

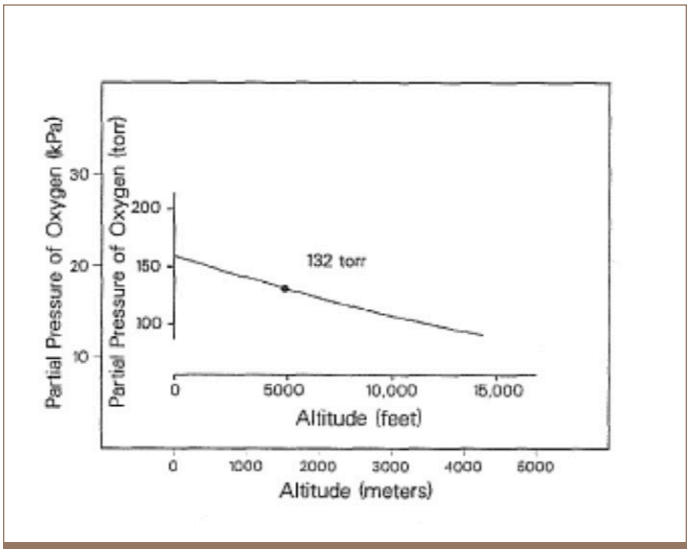

Figure 1 — *Plot of oxygen partial pressure (pO2) (expressed in torr and KPa) with increasing altitude showing the recommended oxygen partial pressure of 132 torr*[9]

Use of other occupational exposure limits

Guidelines on the use of OELs used internationally are very often difficult to source with the OELs often not binding and with very few updated. Questions on their application arise when flying over different states or countries. As an example, the UK based work exposure limits are only applicable between 900-1100 mb, equivalent to 3241 feet to minus 2290 feet.

Use of OELs/ TLVs in the aviation occupational setting

There is wide awareness within the aviation industry and associated sectors that OELs /TLVs should not be applied to the aircraft cabin environment. A few examples applicable to the use of OELs/TLVs as well as the specific case of the use of the threshold limit used for one specific chemical are cited below.

1. Use of exposure limits in aircraft environment

- Aerospace Medical Association: *"OSHA standards (and others throughout the world) are not applicable to aircraft cabin air. Rather they were designed for the industrial workplace."*[10]
- Industry: *"The airliner cabin is a unique environment*

since it is simultaneously occupied by passengers (ie: a segment of the general public) and flight attendants (ie: a segment of the worker population). The standards and guidelines for public exposure are more stringent than occupational levels. Thus it is not appropriate to use occupational standards or guidelines as criteria for the cabin environment."[11]

- ASHRAE: *"Except for industrial workplaces and certain specialized environments, such as spacecraft, indoor air quality standards do not exist for most indoor or confined environments, including aircraft cabins."*[12]
- SAE*: "Occupational and public exposure limits apply only to exposures to a single chemical at a time. They do not reflect the actual situation in aircraft cabins, where contaminants may be present in a blend, and the possible effects of altitude on toxicity mechanisms. Also, exposure standards or limit values do not exist for all chemical species, or the various possible isomers."*[13]
- Manufacturer: *"Existing standards also do not address the specific environment of the aircraft cabin in detail, if at all. The aircraft cabin environment is unique when compared to other indoor spaces…"*[14]
- EASA: *"The conditions in cabin air may differ from the standard conditions on which exposure limits are normally based, for example the air pressure, humidity and longer working hours. These aspects need further consideration. In addition, also possible effects relating to mixture toxicology need further investigation."*[15]
- Industry: *"Typical concentrations found in aircraft can cause transitory symptoms in healthy individuals questioning the adequacy of current standards."*[16]
- UK House of Lords: *"What exposure standards currently apply to any synergistic effects of simultaneous exposure to numerous chemicals which may be experienced by aircraft passengers and crew during a contaminated air event in a reduced pressure environment? Answer: None"*[17]

2. Application of exposure limits—general

- *HSE: "WELs are British occupational exposure limits and are set in order to help protect the health of workers…WELs are approved only for application to people at work"*[18]
- FAA*: "The chemicals found in the carbonaceous material may not necessarily be individually toxic at the found concentrations, but if they are mixed together at those concentrations, the mixture might be highly toxic."*[19]

3. Use of exposure limit for tri-ortho-cresyl-phosphate (TOCP)

- Mobil: *"One might incorrectly imply that TOCP standards are adequately protective for products containing TOCP. However, TCP consists of a mixture of isomers.… This calls into question the adequacy of exposure standards which rely only upon the evaluation of the concentrations of the tri-o-isomer of TCP in the atmosphere. It is possible that the standard promulgated by US OSHA has been based upon the assumption that the tri-o-isomer was primarily or solely responsible for the neurotoxic properties of TCP."*[20]
- Mobil*: "There was very little difference between the activities of TCP &TOCP…..We are under the impression that a commonly held opinion is that TCP with TOCP levels below 1% is not neurotoxic. Our results indicate that TOCP level in TCP is not a reliable indicator of potential neurotoxicity…. There is confusion over the appropriateness of using the TOCP level as an indicator of neurotoxic potential. After considering the weight of all available evidence, both published and our new data, we concluded that EPA and other users of TCP as a lubricant additive should be informed of our results."*[21]
- Scientist*: "'Previous calculations of the toxic human dose were based on the amount of ortho cresol contained in a preparation and related this amount to TOCP, in belief that the bound proportions of meta-cresol and para-cresol have no effect on the toxicity of the total preparation. However since the meta and para isomers that are present can cause the formation of the mono-ortho and diortho esters.… The toxicity of the mixed esters is much greater than*

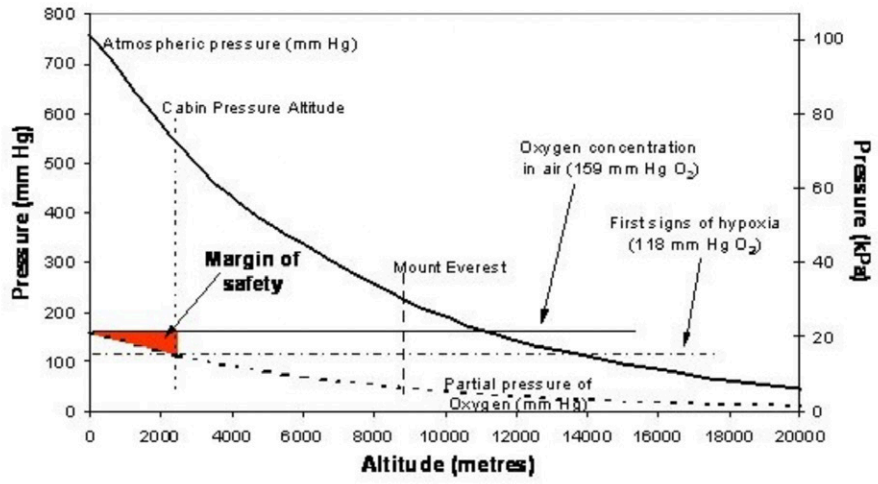

Figure 2 — Pressures and oxygen concentrations at altitude[24]

the TOCP, the old method of calculation, is invalid."[22]

- WHO: *"Because of considerable variation among individuals in sensitivity to TOCP, it is not possible to establish a safe level of exposure … Both the pure ortho isomer and isomeric mixtures containing TOCP are, therefore, considered major hazards to human health."*[23]

Hypoxic environment

The minimum oxygen concentration for work is around 136 mm Hg O2 in air at seal level. A minimum partial pressure of oxygen of 118 mmg Hg (equivalent to an altitude of around 8000 feet/ 2438 m), is required to prevent the aircraft cabin becoming hypoxic during normal operations. There is little margin of safety in people working at altitude and as such workers may be beginning to become hypoxic (*Figure 2*).[24]

On-going industry position

Despite the clear appreciation on how exposure limits should be used and the limitations regarding their use in the aviation setting, many working within the aviation industry continue to rely on the use of measurements referenced to OELs and TLVs. For example the current European FACTS cabin air quality study describes the main purpose being to investigate the quality of the air and the impact on crew and passenger health *"in light of the relevant European legislation on the quality of indoor air and professional exposure limits."*[25,26] A focus continues to remain on TCP and ToCP rather than the complex mixture.[6,27,28] Although there are no OELs or TLVs for the non ortho isomers of TCP it is still suggested that the "*The TCP concentrations (para and meta isomers only) detected on all investigated flights were well below the internationally established toxicological thresholds for harm to human health."*[6]

Complex mixtures

The inappropriate reliance on exposure limits and thresholds, rather than the complex mixture has been increasingly recognized. Exposure to mixtures of contaminants well below levels recommended in currently available exposure standards may still generate adverse effects as the contaminants can act in synergy or the standards may not have incorporated more recent scientific or medical evidence.[29] The application of conventional occupational health and safety procedures to the specialized aircraft environment are inappropriate.[29]

The use of a 'one chemical at a time' approach, rather than focusing on the toxicology of complex mixtures will not address human health problems being identified in the aircraft cabin.[30]

CONCLUSIONS

Threshold limit values and occupational exposure limits should not be applied to the aircraft cabin environment, particularly in relation to aircraft contaminated ventilation air supplies, commonly known as bleed air. This environment is subject to reduced partial pressure of oxygen and involves complex heated mixtures. The environment is unique without the possibility to escape and is one in which both passengers and aircrew are present. The aircraft cabin should not be compared to ground-based workplaces. Avoidance under the hierarchy of controls should be a key factor considered.

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