“Aerotoxic Syndrome”

Cabin Fume Events – Results of Investigations

Professor Michael Bagshaw
King’s College London
Health-Related Symptoms as a Function of Flight Length

Average rating (1-7 scale)
1=Extremely great extent
7=Not at all

All statistically significant p<0.01
Flight Deck Air Quality
Environmental Control System

• Performs multiple functions and sustains life

• Carefully engineered to provide superior cabin air quality

• Fully automatic

• Complex aircraft features allow conversion of the hostile conditions outside the aircraft’s shell to a comfortable, safe environment inside
Harvard Compares Boeing 777 to Buses, Trains, Subways

- **CO₂**:
  - Total VOCs with Ethanol
  - VOCs without Ethanol

- **CO**:
  - Parts per million by volume

- **Microbial Aerosols (Bacteria)**:
  - Parts per billion
  - Colony forming units per cubic meter

- **Particulates**:
  - Respirable suspended particulates

- **Relative Humidity**:
  - Percent

- **NO₂**:
  - Parts per billion

Legend:
- OSHA
- Buses
- Trains
- Subways
- 777/Aircraft
A fume event occurs when bleed air used for cabin pressurization and air conditioning in a pressurized aircraft is contaminated by chemicals such as engine oil, hydraulic fluid, anti-icing fluid and other potentially hazardous chemicals including cargo spills.

Turbine engine oil is an irritant and contains neurotoxic chemicals such as tricresyl phosphate. No conclusive evidence exists that engine oil contains sufficient quantities of such chemicals to cause long term damage.

Hydraulic fluid is extremely irritating, particularly to the eyes, which creates a hazard to pilots during a fume event. Non-toxic and does not cause lasting damage.

Anti-icing fluid has a strong smell, but is not very irritating or toxic.
DEFINITIONS

*Australian Transport Safety Bureau (ATSB)*

Most common source of aircraft fumes and smoke -

Systems issues, primarily relating to failure or malfunction of electrical and auxiliary power unit systems

Other common source –

Equipment and furnishings (such as air conditioning and galley equipment)
Bleed Air Contamination

- Contaminant control in cabin is mainly based on exchange with outside air and filtration of recirculated air.
- Clean bleed air is a prerequisite.
- Bleed air can be contaminated with engine/ APU lubricants in case of:
  - inappropriate design of sealing between bearing housings and air flow.
  - careless or incorrect maintenance.
Engine Lubricating System

Positive air pressure / air flow into lubricating system to avoid ingress of oil into the main air flow. Oil is separated from vent air coming from the bearing compartment.
Engine Vent Air System

Vent air outlet (after oil separation)
Fume Events (UK typical year)

- Fume events in approx 0.05% of flights (1 in 2000)

- UK CAA Mandatory Occurrence Reporting (MOR) System
  - 116 reports from 1.3 million passenger and cargo flights

- Global airline passenger traffic -
  - International 831 million
  - Domestic 1,249 million

- UK professional pilot population approx 20,000
UK Prevalence of ‘Aerotoxic Syndrome’

- UK CAA Medical Dept database of pilots connected with this issue
  
  - In the year 2013 - 28 pilots (of 20,000)
    
    - 14 fit
    
    - 14 unfit (or passed retirement age)

No new cases known to UK CAA since June 2012
Contaminants – In-service example Airbus LR (1997)

- Contaminants identified not unique to cabin environment but to living space or other means of transportation
- Contamination below guideline levels, even with safety factor applied
- Majority of VOC sources are linked to the occupants and activities within the cabin (Ethanol, Acetone,...)

Dechow, Sohn, Steinhanses (1997)
Chemosphere
Contaminants — In-service studies

• University of British Columbia: van Netten (1998)
  • Air Quality measurements on a test flight on BAe146-200 with leaking engine
  • No substance could be found in a harmful concentration even though oil smell was evident
  • TCP could not be detected

• British Airways/BRE (2001)
  • B757 concentration of oil compounds in cabin air <100 ppb (00.00125mg/m³)
  • [Well below toxicological threshold for humans (0.1 mg/m³ over 8hr)]

  • BAe146 & older Boeing aircraft tested for oil vapours - different phases of flight
  • Hardly any trace of oil vapour detected in cabin air
  • No air pollutant exceeded recommended health limits
Contaminants — In-service studies

- UK DfT Cranfield Study (2010) - B757, A320/1, A319, BAe146 aircraft
  - A fume event reported at top of climb phase (B757, RR535c)
  - BRE detected a sharp, brief rise in UF particles (>500,000 particles per cm³)
  - Slightly higher (but very low) concentrations of engine oil components detected by BRE (0.5 µg/m³ JEO, 0.04µg/m³ TCP) at top of climb
  - All levels well below occupational exposure limit values

- UK DfT Institute of Occupational Medicine (2012)
  - Wipe study for potential contaminant residues on internal surfaces
  - 86 sample sets - Aircraft, ground vehicles, offices
  - TBP, BDPP, DBPP levels similar in aircraft to control vehicles
  - TCP levels slightly higher in aircraft than in control vehicles
  - Estimates of air concentrations consistent with other studies
Contaminants — In-service studies

- German Institute for Prevention & Occ Medicine – Schindler et al (2013)
  - 332 urine samples from crew members reporting fumes/odours
  - No ToCP metabolites above limit of detection (LOD)
  - One sample - metabolites of TmCP and TpCP near LOD
  - Health complaints cannot be causally associated with ToCP exposure in cabin air

- TNO KLM B737 (2013)
  - 20 flights by 9 different KLM B737 aircraft
  - Average total TCP 7ng/m³
  - ToCP entirely absent (health risk level 100,000ng/m³)
  - Levels of all TCPs much lower than in previous international studies
  - Highly unlikely that such levels constitute a health risk
Studies of Cabin Air ToCP

• Max reported peak - 0.005mg/m³

To give some idea of scale:

• For TCP 1 ppb ≅ 0.007 mg/m³

• 1 ppb ≅ 1 second in 32 years (16,819,200 secs)
Alveoli: Site of Gas Exchange

- **Bronchiole**: Carries air into the alveolar sacs
- **Pulmonary venule**: Carries oxygen-rich blood back to the pulmonary veins
- **Capillary bed**: Network of thin-walled vessels where oxygen enters the blood and carbon dioxide leaves
- **Lymphatic vessel**: Drains fluid from intercellular spaces back to the blood via a network of vessels
- **Pulmonary arteriole**: Carries deoxygenated blood to capillary bed for gas exchange to take place
Fick’s Law

The rate of gas diffusion through a tissue medium is proportional to the tissue area and the difference between the gas partial pressures on the two sides, and inversely proportional to the tissue thickness.
Dalton’s Law

The total pressure of the gas mixture is equal to the sum of its partial pressures.
Engine oil organophosphates
Cabin Air Quality
Incidents
Project Report

Occupational Health Research Consortium in Aviation
University of Oregon, Eugene, OR 97403
University of British Columbia, Vancouver, BC Canada V6T 1Z4
University of California- San Francisco, San Francisco, CA 94143
Association of Flight Attendants-Communications Workers of America, Washington, DC 20001

Airliner Cabin Environment Research
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University of California- Berkeley, Berkeley, CA 94720

Table 9. Percent of TCP isomers per unit weight in oils and fluids as well as relative percent of each isomer to the total.

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>% TCP total</th>
<th>Rel. % 000 TCP</th>
<th>Rel. % mmm TCP</th>
<th>Rel. % mmp TCP</th>
<th>Rel. % mpp TCP</th>
<th>Rel. % ppp TCP</th>
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</thead>
<tbody>
<tr>
<td>Aeroshell 560</td>
<td>2.23</td>
<td>0.02</td>
<td>29.53</td>
<td>49.05</td>
<td>21.34</td>
<td>0.09</td>
</tr>
<tr>
<td>BP 2389</td>
<td>2.80</td>
<td>0.01</td>
<td>15.68</td>
<td>49.63</td>
<td>34.39</td>
<td>0.30</td>
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<tr>
<td>BP 2197</td>
<td>2.85</td>
<td>0.01</td>
<td>29.73</td>
<td>48.45</td>
<td>21.73</td>
<td>0.09</td>
</tr>
<tr>
<td>Mobil II</td>
<td>5.23</td>
<td>&lt;0.01</td>
<td>31.48</td>
<td>47.04</td>
<td>21.37</td>
<td>0.11</td>
</tr>
<tr>
<td>Used BP 2380</td>
<td>5.10</td>
<td>&lt;0.01</td>
<td>29.81</td>
<td>47.67</td>
<td>22.40</td>
<td>0.12</td>
</tr>
<tr>
<td>Bulk BP 2380</td>
<td>4.70</td>
<td>&lt;0.01</td>
<td>32.22</td>
<td>47.64</td>
<td>20.04</td>
<td>0.10</td>
</tr>
<tr>
<td>Chevron Hyjet</td>
<td>0.00</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Mobil 291</td>
<td>5.59</td>
<td>&lt;0.01</td>
<td>24.83</td>
<td>47.22</td>
<td>27.76</td>
<td>0.19</td>
</tr>
<tr>
<td>Skydrol LD-4</td>
<td>0.00</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Skydrol 500 B-4</td>
<td>0.00</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
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<tr>
<td>Exxon O-156</td>
<td>4.48</td>
<td>&lt;0.01</td>
<td>29.11</td>
<td>48.19</td>
<td>22.59</td>
<td>0.12</td>
</tr>
<tr>
<td>Mobil 254</td>
<td>4.99</td>
<td>&lt;0.01</td>
<td>33.58</td>
<td>46.50</td>
<td>19.85</td>
<td>0.09</td>
</tr>
</tbody>
</table>
Organophosphates (OPC) \( (n = 125) \)

<table>
<thead>
<tr>
<th>compound name</th>
<th>acronym</th>
<th>average</th>
<th>median</th>
<th>min</th>
<th>max</th>
<th>75. percentile</th>
<th>95. percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triisobutylphosphate</td>
<td>TiBP</td>
<td>0.06</td>
<td>0.04</td>
<td>n. d.</td>
<td>0.29</td>
<td>0.07</td>
<td>0.18</td>
</tr>
<tr>
<td>Tributylphosphate</td>
<td>TBP</td>
<td>0.79</td>
<td>0.67</td>
<td>0.04</td>
<td>3.50</td>
<td>0.93</td>
<td>1.79</td>
</tr>
<tr>
<td>Tris(2-chloro-ethyl)phosphate</td>
<td>TCEP</td>
<td>0.05</td>
<td>0.04</td>
<td>n. d.</td>
<td>0.43</td>
<td>0.07</td>
<td>0.12</td>
</tr>
<tr>
<td>Tris(chloro-isopropyl)phosphate</td>
<td>TCPP</td>
<td>0.11</td>
<td>0.06</td>
<td>n. d.</td>
<td>0.68</td>
<td>0.17</td>
<td>0.34</td>
</tr>
<tr>
<td>Tris(1,3-dichloro-isopropyl)phosphate</td>
<td>TDCPP</td>
<td>0.02</td>
<td>0.00</td>
<td>n. d.</td>
<td>1.35</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>Triphenylphosphate</td>
<td>TPP</td>
<td>0.02</td>
<td>0.01</td>
<td>n. d.</td>
<td>0.19</td>
<td>0.02</td>
<td>0.04</td>
</tr>
<tr>
<td>Tris(butoxy-ethyl)phosphate</td>
<td>TBEP</td>
<td>0.03</td>
<td>0.01</td>
<td>n. d.</td>
<td>0.20</td>
<td>0.03</td>
<td>0.12</td>
</tr>
<tr>
<td>Diphenyl-2-ethylhexylphosphate</td>
<td>DPEHP</td>
<td>0.03</td>
<td>0.02</td>
<td>n. d.</td>
<td>0.22</td>
<td>0.03</td>
<td>0.07</td>
</tr>
<tr>
<td>Tris(ethyl-hexyl)phosphate</td>
<td>TEHP</td>
<td>0.03</td>
<td>0.01</td>
<td>n. d.</td>
<td>0.34</td>
<td>0.02</td>
<td>0.21</td>
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<tr>
<td>Tri-m-cresylphosphate</td>
<td>TmCP</td>
<td>0.005</td>
<td>0.002</td>
<td>n. d.</td>
<td>0.128</td>
<td>0.004</td>
<td>0.015</td>
</tr>
<tr>
<td>Tri-mmp-cresylphosphate</td>
<td>TmmpCP</td>
<td>0.007</td>
<td>0.002</td>
<td>n. d.</td>
<td>0.176</td>
<td>0.005</td>
<td>0.021</td>
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<tr>
<td>Tri-mpp-cresylphosphate</td>
<td>TmppCP</td>
<td>0.004</td>
<td>0.001</td>
<td>n. d.</td>
<td>0.107</td>
<td>0.003</td>
<td>0.011</td>
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<tr>
<td>Tri-p-cresylphosphate</td>
<td>TpCP</td>
<td>0.001</td>
<td>0.0005</td>
<td>n. d.</td>
<td>0.014</td>
<td>0.001</td>
<td>0.002</td>
</tr>
<tr>
<td>Trixylylphosphate</td>
<td>TXP</td>
<td>0.23</td>
<td>0.23</td>
<td>0.01</td>
<td>0.44</td>
<td>0.34</td>
<td>0.42</td>
</tr>
</tbody>
</table>

Rosenberger, W., S. Netz-Piepenbrink, and R. Wrbitzky.  
"Determination of mono- and diortho tricresyl phosphates in indoor air of aircraft."  
Gefahrstoffe Reinhaltung Der Luft 73.4 (2013): 138-143.
Theoretical Contaminant Levels

• RB211 - total engine oil possible in bleed air 0.4kg

• 3% TCP of which <0.2% ortho-isomers & 0.1% ToCP

• Worst case dump of total oil into bleed air
  • Peak cabin atmospheric concentration 0.025 mg/m³
    (short term - rapidly decreasing)

• cf current workplace 8 hr limit 0.1 mg/m³

*Airbus evidence to UK House of Lords Select Committee 2007*
• Concerns about engine oil toxicity largely based on the tri-o-cresyl phosphate isomer content

• The o-cresyl isomers have been found to be present almost exclusively in engine oil as the more toxic mono-o-cresyl isomers in the concentration range 13–150 mg/L

• Therefore, as a general principle, the toxicity of TCP should be based on the mono-o-cresyl isomer content rather than on the tri-o-cresyl phosphate content

G. De Nola, J. Kibby, W. Mazurek
Determination of ortho-cresyl phosphate isomers of tricresyl phosphate used in aircraft turbine engine oils by gas chromatography and mass spectrometry
The Australian Transport Safety Bureau is investigating a 17 April incident aboard a United Airlines Boeing 787-9, during which fumes were detected in the cabin. Aircraft N36962 had entered the cruise phase of a Sydney-San Francisco flight when the crew raised the alarm, it says. The GE Aviation GEnx-1B-powered Dreamliner returned to Sydney and landed safely.

Flight International p6, 26 April-2 May 2016
Questions ..... ??