Aircraft cabin air contamination and oil seals

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Bleed air = Cabin air
1954 – Dash 80 (Boeing 707)

Turbo compressors
The J57 (JT3) Engine was the first Pratt & Whitney-designed turbojet.

B-52 and the F-100 – Bleed Air
27 May 1955 - Caravelle (1st Flight)
The problem

- Synthetic engine oils
- Leakage past seals into heated compressor/ bleed air
- Compromising flight safety
- Adverse health effects
- Other substances can leak into bleed air - hydraulic/deicing fluids...
## EU/UN Hazard Classifications (CLP /REACH)

### Oil, hydraulic, deicing fluids: HAZARDS

<table>
<thead>
<tr>
<th>Harmful if swallowed/dermal:</th>
<th>Eye/skin irritant &amp; ? Respiratory irritant</th>
</tr>
</thead>
<tbody>
<tr>
<td>May (suspected) cause damage fertility or harm the unborn child</td>
<td>Skin sensitizer</td>
</tr>
<tr>
<td>Single exposure &amp; repeated target organ toxicity - nervous system</td>
<td>Very toxic by inhalation</td>
</tr>
<tr>
<td>May cause genetic defects</td>
<td>May cause allergy/asthma or breathing difficulties if inhaled</td>
</tr>
<tr>
<td>May (Suspected) of causing cancer</td>
<td>May cause drowsiness or dizziness</td>
</tr>
</tbody>
</table>

**TXP – Substance of Very High Concern (SVHC) – REACH**

May cause harm to the unborn/Impair fertility
Issues

✈ Exposures occurring in normal ops
  – TCP being found between 25% - 85-90%

✈ Events are said to range from Very rare to very frequent
  – Oil fume events – 1% of flights (COT, 2007)
  – Low level oil leaks as a function of design/operation using bleed air system (Michaelis 2010)

✈ Science is catching up: Treon (1954); Baker (2012); Hausherr (2014); Abou-Donia (2013); Kojima (2014); Reneman (2015); Michaelis (2010)...... & many published papers

✈ Temporal relationship between “perceived” fume events and acute ill health (COT 2013)

✈ Wide variety of industry actions
Current Industry initiatives (limited examples)

✈ EASA – air monitoring & oil pyrolysis studies
✈ REACH review of TCP
✈ Dutch Government review of TCP, Aerotoxic syndrome
✈ CEN – European cabin air standard- under devel
✈ ICAO – Fume events guidance material
✈ IATA - Guidance on medical response to fume events
✈ Coroners court hearing- on going
✈ EU Cleanskys/ Futuresky – Electric ECS; fumes
✈ Various solution in development – sensors, filtration....
✈ NASA/FAA, USAF- VIPR program
✈ More electric aircraft
✈ European Cockpit Assoc – Position statement
Flight safety

✈ ICAO (2015)

“particular concerns have been raised regarding the negative impact on flight safety when crew members are exposed to oil or hydraulic fluid fumes or smoke, and experience acute symptoms in flight.”

✈ Impairment is frequent- 32% (Michaelis 2010)

✈ Safety degradation widely recognized

✈ Under-reporting of events is extensive

✈ Crews not acting appropriately
Adverse effects

**BAe 146 adverse health effects**

- Lost medical/health: 13%
- Medium-long-term effects: 32%
- Immediate/short-term reported adverse effects: 44%
- Aware of exposures: 63%
- Chronic ill health: 88%

Aircrew/passengers are reporting:
Chronic neurological, respiratory disease consistent with exposure to jet engine oils including OPs

Cancers: Higher than population averages

**Aerotoxic Syndrome** is a valid term
- causative relationship exists
- Published literature ✔

Oil leakage

There is a ‘general acceptance’ that cabin air can be contaminated by compounds released from pyrolysed oil from engines and APUs.

AAIB Bulletin 5/2013 - EW/G2012/10/12
Oil leakage seen in 3 ways

1. Seal/bearing failure/ minor systems failure  - Includes worn seals/ overfilled sumps

2. Seal/bearing failure, maintenance irregularities or design deficiency
   
   Both Very Rare/infrequent

3. Design – Sealing across whole operating range incl. transients – Rarely referenced but normal
Design

- Seals required to seal across whole engine operating range, including transient manoeuvres – RR, 2003
- All seals and bearings leak – BAe, 2000
- Leakage – Design feature using bleed air - CASA, 2000
- Oil seals – less efficient during transients – BAe, SAE
- Improvements in design continue/recommended
- Low level leakage at certain phases of flight
- Residual contamination
Normal ops – Low level leakage

→ Oil seal leakage is reported to occur during certain events such as engine switching, top of descent with chronic vapours ‘continuously leak through seals in tiny amounts’

De Boer, 2014

→ Oil leaking from bearings can be either ‘slowly varying and somewhat continuous or sporadic and quite intermittent.’ – ACER 2013

→ Background low levels of oil additives and other substances expected in normal flight- Battelle/spengler12, Nagda, 2003
Labyrinth (clearance) seals

- Tight clearances
- Controlled leakage of air to reduce pressure/keep oil in sump
- Higher pressure on outside
- Prevents oil leaking out

The Jet Engine, Rolls-Royce
Labyrinth (clearance) seals

- Often used to seal bearing compartments
- Low cost, simplicity, reliability, reduced wear
- High air leakage in / oil leakage out
- Do not in isolation provide complete barrier to leakage
- Do not respond well to dynamics – Incr in seal clearances
  - Shaft excursions on stop/start & other transients
Mechanical Carbon Seals

- Precision flat faces
- Rely on positive pressure differential to load carbon elements to minimize wear and leakage
- Wear is critical
Mechanical Carbon Seals

• Often used to seal bearing sumps
• More expensive, complex, maintenance intensive, shorter life, finite wear
• Excessive wear of faces during transients
• Oil between faces — Typically 1 μm thick –
  • thick enough to provide lubrication/ long life
  • Thin enough to minimize oil leakage into compressor
• Will leak a very small amount of oil vapour (few ppm -10cc/min)
• Flat faces: Coking; distortion with thermal/ pressure effects
  — Increase leakage
• Unknown if labyrinth back ups/presealing, seal arrangements, positive shut-down devices....
Common

- Both seals rely upon compressor pressurized air over seal
- Responsive to variations in engine operating conditions
- Sealing bearing compartments is difficult
Common assumptions

✈ Both Labyrinths & mechanical will not leak oil if:

✈ Pressure higher outside chamber (positive) with leakage always into chamber

✈ Absence of seal failure

✈ Avoidance of reverse pressures

BUT
Oil leaks more than realised

- Positive gradient is difficult to obtain under all operating conditions (Palsulich, 69)

- Oil may flow opposite positive pressure gradient (low to high) (Palsulich, 69, Nau, 64, Flitney 14) - Dalton’s law of partial pressures

- Reverse pressures will allow leakage in opposite direction
Industry awareness examples

✈ Shaft seals “must function as seals – NOT flow restrictors.” – Bill, NASA, 1991

✈ “Air oil/seals must be improved now!” – High temps, oil coking, incorrect tracking leading to smells in cabin, wear, high oil consumption - Ullah NASA, 1995

✈ Future research needs include the transient behaviour of seals. Ullah, 1995

✈ Shaft seal technology has not kept pace with advances in major engine components - AGARD, 1978
Industry awareness examples

✈ ‘the major part of the consumption representing loss of liquid oil arising from permissible leakage past certain seals, escape of mist or aerosol through breathers and losses incurred during filter inspections in service. These are made good by “topping up” the system with fresh oil.’ (Edge & squires, Rolls-Royce1969)
issues

✈ Seals leak – emission/leak?
✈ Low concentrations of oil often seen as safe
✈ Strong industry awareness seals leak
✈ Strong focus on secondary air leakage rates/ performance/ not oil leakage
✈ Reluctance by OEMs to change from labyrinth seals for mainshaft sealing to carbon seals, more advanced seals
## Overall seal performance (1)

<table>
<thead>
<tr>
<th>Seal type</th>
<th>Knife edge</th>
<th>Brush seal</th>
<th>Radial contact seal</th>
<th>Radial lift seal</th>
<th>Axial contact seal</th>
<th>Axial lift seal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Oil consumption</strong></td>
<td>High air leakage gives high oil consumption 50gm/s</td>
<td>High air leakage gives high oil consumption</td>
<td>High air leakage gives high oil consumption 3.5gm/s</td>
<td>Moderate air leakage gives moderate oil consumption</td>
<td>Low air leakage gives low oil consumption</td>
<td>Low air leakage gives low oil consumption 0.5gm/s</td>
</tr>
<tr>
<td><strong>Reverse pressure gives Oil pollution</strong></td>
<td>High oil loss, oil pollution in cabin</td>
<td>High oil loss, oil pollution in cabin</td>
<td>High oil loss, oil pollution in cabin</td>
<td>High oil loss, oil pollution in cabin</td>
<td>High oil loss, oil pollution in cabin</td>
<td>No oil loss in reverse pressure, no oil pollution</td>
</tr>
</tbody>
</table>

Solutions

- Bleed free aircraft
- Better oil seals
- Filter/clean bleed air
- Detection systems
- Less toxic oils
- Seal providers brought in at the start of the design process
Thank you

Further information:

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