AIRCRAFT DESIGN AND SYSTEMS GROUP (AERO)

Aircraft Cabin Air – Quality or Contamination?

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Personalversammlung "Kabine", Deutsche Lufthansa AG
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Aircraft Cabin Air – Quality or Contamination?

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Introduction
Introduction

**Definition: Aircraft Cabin Air**

A mixture of outside as well as recirculated and filtered air. In unpressurized aircraft cabins the air is at ambient pressure. In pressurized cabins the air is at a pressure equivalent to below 8000 ft (referring to the ICAO Standard Atmosphere). In most aircraft, the air temperature is controlled. Aircraft flying at high altitude usually show low relative humidity.

Adapted from: http://aircrewwhealth.com/Topics/hazards/cabinair.htm
Introduction

**Definition: Contamination**
The process of making a material unclean or unsuited for its intended purpose, usually by the addition or attachment of undesirable foreign substances.

Adapted from: http://en.wiktionary.org/wiki/contamination

The presence of a minor and unwanted constituent (contaminant). Related to health: A harmful intrusion of toxins or pathogens e.g. in food, water, or air.

Adapted from: http://en.wikipedia.org/wiki/Contamination

**Definition: Quality**
Degree to which a set of inherent characteristics fulfills requirements.

ISO 9000
Health Effects: Occupational Health & Flight Safety

Health effects may be experienced soon after exposure or, possibly, years later:

- **Long-term health effects:**
  - to passengers
  - to crew => **occupational health** (OH)
    - usually related to
      - Time-Weighted Average (TWA)
      - Permissible Exposure Limits (PEL)

- **Immediate health effects:**
  - to passengers
  - to cabin crew
  - to cockpit crew => **flight safety implications** can lead to:
    - injury or death of
      - passenger
      - crew

(Eurofins 2017, EASA CS-25)
Introduction

**Potential Concerns Related to Air Quality**

- **Cabin Pressure**: Can effect people with cardio-respiratory diseases from lack of oxygen.
- **Relative Humidity**: Temporary drying of skin, eyes, and mucous membranes.
- **Carbon Monoxide**: High concentrations during air-quality incidents. Frequency is believed to be low. CS 25.831: Concentration must be lower than 50 ppm.
- **Carbon Dioxide**: Concentrations are generally below FAA regulatory limits. Associated with increased perceptions of poor air quality. CS 25.831: Concentration must be lower than 0.5%.
- **Ozone**: Elevated concentrations on aircraft without ozone converters. Airway irritation and reduced lung function. CS 25.832: Concentration < 0.25 ppm resp. 0.1 ppm.
- **Pesticides**: From aircraft “disinsection” with pesticides.
- **Engine Oil**: Fumes from hot engine oil may enter the cabin via the bleed air system.
- **Hydraulic Fluids**: Frequency of incidents is expected to be relatively low. Mild to severe health effects.
- **Deicing Fluid**: Hazardous substance. Skin sensitizing and irritant.
- **Airborne Allergens**: Exposure frequency is not known. Irritated eye and nose; sinusitis; acute increases of asthma; possible anaphylaxis.
- **Nuisance Odors**: Can be present on any flight.

Adapted from: http://aircrewwellness.com/Topics/hazards/cabinair.htm
Introduction

Potential Concerns Related to Water Quality

- Original Water Quality
  Depending on urban water management
- Purity of Tank and Water Lines
  Depending on aircraft potable water system maintenance
- Pesticides
  Aircraft "Disinsection" with pesticides
- Engine Oil
  Fumes from hot engine oil may enter water via the bleed air system.
- Hydraulic Fluids
  Hydraulic fluids are unlikely to enter the water via the bleed air system.
### Introduction

<table>
<thead>
<tr>
<th>Potential sources</th>
<th>Potential impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine start during push back</td>
<td>Exhaust gases (e.g., CO, CO₂, NOₓ, fuel, particles)</td>
</tr>
<tr>
<td>Bleed air switch off during engine start</td>
<td>Short time increase of CO₂</td>
</tr>
<tr>
<td>Cabin cleaning in general</td>
<td>VOC, e.g. alcohols, flavors (terpenes), aldehydes</td>
</tr>
<tr>
<td></td>
<td>Residual of tetrachloroethene</td>
</tr>
<tr>
<td>Interior cleaning</td>
<td>Ozone, particularly in cruise</td>
</tr>
<tr>
<td>No ozone converters installed</td>
<td>1,2-Propanediol (major constituent) and various additives (e.g., dyes, thickener, antioxidants)</td>
</tr>
<tr>
<td>De-icing fluids</td>
<td>Exhaust gases (e.g., CO, CO₂, NOₓ, fuel, particles)</td>
</tr>
<tr>
<td>Aircraft traffic at the airport</td>
<td>Exhaust gases (e.g., CO, CO₂, NOₓ, gasoline, particles)</td>
</tr>
<tr>
<td>Car traffic at the airport</td>
<td>Emission of CO₂, various VOCs, offensive smell</td>
</tr>
<tr>
<td>Passengers</td>
<td>Smell, VOC from cleaning products</td>
</tr>
<tr>
<td>Restrooms</td>
<td>VOC/SVOC, particulate organic matter (POM), flame retardants e.g. organophosphates</td>
</tr>
<tr>
<td>Furnishings</td>
<td>Various VOCs, lubricants</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Oil base stock, organophosphates, POM</td>
</tr>
<tr>
<td>Lubricants</td>
<td>e.g. Tributyl phosphate (TBP), triphenyl phosphate (TPP)</td>
</tr>
<tr>
<td>Hydraulic fluids</td>
<td>Tricresyl phosphate (TCP), trixylyl phosphate (TXP), Amines</td>
</tr>
<tr>
<td>Engine oils</td>
<td>VOCs, organic acids, aldehydes, CO, CO₂, potential unknown products</td>
</tr>
<tr>
<td>In case of thermal degradation</td>
<td>(EASA 2017b)</td>
</tr>
</tbody>
</table>
All Aviation Fluids: Ingestion from the Ground!
All Aviation Fluids: Ingestion from the Ground!

**Intake Vortices**

- Due to gravity everything (**all aviation fluids**) will be on the ground eventually.
- Due to jet engines suction everything from the ground will be **in the** bleed and **cabin air**.

See also: [https://youtu.be/p5l3fD2WIQc](https://youtu.be/p5l3fD2WIQc)
Engine Oil => Cabin Air? Yes
Air Conditioning Technology

Major Component Location

Adapted from (AMM B737)
Air Conditioning Technology

Air Conditioning Basics

Temperature Control, Pressure Control, Ventilation

1) compress the air
2) cool the air

=> Temperature Control

3) release the air
=> Pressure Control:
out > in: pressure goes down
in > out: pressure goes up

Adapted from (NRC 2002)
Air Conditioning Technology

Air Conditioning with Recirculation

Adapted from (NRC 2002)
Air Conditioning Technology

"Bleed Air" Generation and Treatment

compress and cool the air

"Bleed Air" is "precious air" taken off the engine compressor – air which was initially intended to be used for the engine cycle

1) compress the air
2a) cool the air
2b) cool the air

Adapted from (FCOM A340)
Air Conditioning Technology

Temperature Control

2b) Air Cooling
Temperature Control (i)

Dieter Scholz:
A/C Cabin Air – Quality or Contamination?
Deutsche Lufthansa AG

Personalversammlung "Kabine"

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

20.11.2017, Slide 17
Aircraft Design and Systems Group (AERO)
Air Conditioning Technology

Cabin Air Distribution

A320

Cabin outlets

Cabin ambient air to underfloor area

(GENFAM A320)
Jet Engine

**Engine Overview**

- Fan
- High-pressure compressor
- High-pressure turbine
- High-pressure shaft
- Low-pressure compressor
- Low-pressure shaft
- Combustion chamber
- Low-pressure turbine
- Nozzle

https://upload.wikimedia.org/wikipedia/commons/7/77/Turbofan_operation_lbp.svg
Jet Engine

Engine Overview

Engine Alliance GP7000

Download from: https://goo.gl/images/gYIW31

bearing (example)
Jet Engine

Jet Engine Bearing

(Exxon 2016b)
Judging Jet Engine Oil Based on Warnings Given by Manufacturer

warning: contains TCP. Swallowing this product can cause nervous system disorders, including paralysis. Prolonged breathing of oil mist, or prolonged or repeated skin contact can cause nervous system effects.

Jet Engine Oil II (Cannon 2016)
Health Effects? => EASA Study 2017: AVOIL

AVOIL – Characterisation of the toxicity of aviation turbine engine oils after pyrolysis (EASA 2017a)
"a ... list of 127 compounds [VOC] was ... identified ... ". The hazard profile is given in Appendix 6:

<table>
<thead>
<tr>
<th>Compound #</th>
<th>Name</th>
<th>CAS</th>
<th>Harmonized classification</th>
<th>Self-classification*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Diethyl Phthalate</td>
<td>84-66-2</td>
<td></td>
<td>NC</td>
</tr>
<tr>
<td>2</td>
<td>1-Nonene, 4,6,8-trimethyl-</td>
<td>54410-98-9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2-Ethylhexyl salicylate</td>
<td>118-60-5</td>
<td></td>
<td>Skin Irrit. 2</td>
</tr>
<tr>
<td>4</td>
<td>Acetophenone</td>
<td>98-86-2</td>
<td>Acute Tox. 4</td>
<td>Eye Irrit. 2</td>
</tr>
<tr>
<td>5</td>
<td>Benzaldehyde</td>
<td>100-52-7</td>
<td>Acute Tox. 4</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Benzene, 1,3-bis(1,1-dimethylethyl)-</td>
<td>1014-60-4</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>7</td>
<td>Heptane, 4-methyl-</td>
<td>589-53-7</td>
<td>Asp. Tox. 1</td>
<td>Skin Irrit. 2</td>
</tr>
<tr>
<td>8</td>
<td>Nonanal</td>
<td>124-19-6</td>
<td>STOT SE 3</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>2,4-Dimethyl-1-heptene</td>
<td>19549-87-2</td>
<td>Asp. Tox. 1</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Decane</td>
<td>110-21-3</td>
<td>Eye Irrit. 2</td>
<td></td>
</tr>
<tr>
<td>124</td>
<td>Isopropyl myristate</td>
<td>110-21-0</td>
<td></td>
<td>NC</td>
</tr>
<tr>
<td>125</td>
<td>Tetradecanoic acid</td>
<td>544-63-8</td>
<td></td>
<td>NC</td>
</tr>
<tr>
<td>126</td>
<td>1-Pentene, 4-methyl-</td>
<td>691-37-2</td>
<td></td>
<td>Asp. Tox. 1 Or Skin Irrit. 2 Eye Irrit. 2 STOT SE 3</td>
</tr>
<tr>
<td>127</td>
<td>2-Cyclopenten-1-one</td>
<td>930-30-3</td>
<td></td>
<td>NC</td>
</tr>
</tbody>
</table>

* according to the largest number of notifiers
NC = not classified for human health effects
NR = not registered under REACH
Jet Engine

Engine Air and Oil System

Normal operation of engine seals:
1. The "drain" discharges oil.
2. The "dry cavity" contains oil.
3. Air and oil leak from bearings into the bleed air.

=> Engines leak small amounts of oil by design!

based on:
Exxon 2016b
Auxiliary Power Unit (APU)

Bearings and Load Compressor

APU GTCP36-300

- An **Auxiliary Power Unit (APU)** is a gas turbine engine.
- An APU will need some form of lubrication (e.i. oil).
- Lubrication needs will be smaller than in aircraft engines, but the APU otherwise experiences the same problems with oil leakage as described for the engine.
Engine Oil => Water? Yes
Aircraft Systems Investigated - Potable Water Tank Pressurization

- Possible bleed air contaminations could reach the potable water passing a filter and a check valve (in flow direction).
Aircraft Systems Investigated - Potable Water Tank Pressurization

- Possible bleed air contaminations could reach the potable water.

FCOM A340: Potable Water System Description
Aircraft Systems Investigated - Potable Water Tank Pressurization

- Possible bleed air contaminations could reach the potable water passing a filter and a check valve (in flow direction).

Training Material **A320**: Potable Water System pressurization.
Aircraft Systems Investigated - **Potable Water System**

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**Water Treatment Module**

The potable water treatment module comprises:
- an inhibition-of-scaling module,
- a heating device.

The inhibition-of-scaling module avoids forming of layers of alkaline earth compounds.

The heating device protects water against freezing.

- **No bleed air used for potable water pressurization**
Hydraulic Fluid => Cabin Air / Water? No
Aircraft Systems Investigated - Hydraulic Reservoir Pressurization

- Hydraulic reservoirs are connected via bleed lines with the potable water tanks.
- Pressurized air is in free contact with the hydraulic fluid surface.
- In flight, hydraulic fluid would need to flow upstream and opposite sense through two check valves to get into the bleed line.
- On the ground, contaminated air with remaining pressure in the reservoir (≈3.5 bar) could flow downstream – but only if check valves allow for wrong flow direction.
Technical Solutions (in the Future?)
Technical Solutions

Ozone Converter

- Ozone concentration increases with altitude.
- Low flying aircraft do not need an ozone converter.
- **Catalytic ozone converters** have found to be effective also in removing VOCs resulting from contaminated bleed air.

Ozone Converter

---

**BASF 2014**

Technical Solutions

Filter in the Recirculation Path

Pall offers Odour/VOC Removal Filters
• "The carbon adsorbent is effective at adsorbing volatile organic compounds (VOC). Test results have shown a removal efficiency of 65% ... 73% when challenged with TCPs in the gaseous phase." (Pall 2011)

Application of Carbon Filters
• HEPA-Carbon filters have been added to 33 A321 aircraft at Lufthansa Group so far. (Lufthansa 2017)
• These filters are located in the recirculation path of the cabin air.

Adapted from (NRC 2002)
Efficiency of Filter in the Recirculation Path

Example calculation:
• With a filtration rate, \( x_{fil} = 0.7 \) (Pall 2011) and a recirculation rate, \( x_{re} = 0.5 \) (A320) the filter in the recirculation path reduces the incoming concentration to 58.9% or around \( \approx 60\% \).

\[
\frac{x_{cont,cab}}{x_{cont,in}} = \frac{1 - x_{re}}{1 - (1 - x_{fil}) x_{re}}
\]

for \( x_{fil} = 1 \):

\[
\frac{x_{cont,cab}}{x_{cont,in}} = 1 - x_{re}
\]
Technical Solutions

Full Filtration
Option: 1

Filtration aft of source (engine / APU). Filtration in recirculation.

\[
\frac{x_{cont,cab}}{x_{cont,in}} = (1 - x_{fil}) f_{recirc}
\]

\[
\approx 0.3 \cdot 0.6 = 0.18
\]

=> reduces incoming pollutant concentrations to \(\approx 18\%\)
Technical Solutions

Full Filtration
Option: 2

Filtration before or directly aft of Pack Flow Control Valve. Filtration in recirculation.

\[ \frac{x_{\text{cont,cab}}}{x_{\text{cont,in}}} = (1 - x_{\text{fil}}) \cdot f_{\text{recirc}} \approx 0.3 \cdot 0.6 = 0.18 \]

\[ \Rightarrow \text{reduces incoming pollutant concentrations to} \approx 18\% \]
Technical Solutions

Full Filtration
Option: 3

Filtration of cold air and of hot trim air. Filtration in recirculation.

Outflow valve

\[ f_{\text{recirc}} = \frac{1 - x_{re}}{1 - (1 - x_{fil})x_{re}} \]

\[ \frac{x_{cont, cab}}{x_{cont, in}} = (1 - x_{fil}) f_{\text{recirc}} \approx 0.3 \cdot 0.6 = 0.18 \]

=> reduces incoming pollutant concentrations to \( \approx 18\% \)
Filtration of air directly before it is entering the respective cabin zone. Filtration in recirculation.

\[ \frac{X_{cont,cab}}{X_{cont,in}} = (1 - X_{fil}) f_{recirc} \]

\[ \approx 0.3 \cdot 0.6 = 0.18 \]

=> reduces incoming pollutant concentrations to \( \approx 18\% \)

- VOC Filter
- Combined HEPA & VOC Filter (HEPA-Carbon Filter)
Cabin Pressurization Principles and Solutions

Overview

- **First Jet Aircraft** used a "blower" or "turbocompressor" (TC). The TC is the coupling of a turbine with a compressor. Bleed air from the engine compressor drives the TC turbine. The TCs compressor compresses outside air to meet the pressurization requirements of the cabin. The hot compressed air needs to be cooled. This can be done with a "vapor cycle system" (as known from the refrigerator).
- **Current Aircraft** make use of bleed air directly. It is compressed so much that it contains enough energy to also drive the pack that cool the bleed air down to temperatures considerably less than 0°C.
- The **Boeing 787** uses electrical power to drive an electric motor to drive a compressor. The energy is extracted from the engine by means of shaft power driving a generator. No bleed air is used. The engine is "Bleed Free".

Solution?

First Jet Aircraft (First Flight, 1958) -> Engine Bleed Air -> Blower -> Aircraft Cabin -> Discharged to Atmosphere

Problem!

Current Aircraft (Since 1963) -> Engine Bleed Air -> Heat Exchanger -> Aircraft Cabin

Solution!

Boeing 787 (First Flight, 2009) -> "Bleed Free" -> Electric Compressor -> Aircraft Cabin

(Michaelis 2010)
Technical Solutions

Electrical (Bleed Free) Cabin Air Supply

Solution B787!

The "Pack" of the B787's Environmental Control System (ECS) is powered by electric motors (M) to compress ambient air up to cabin pressure and to push the air through the heat exchangers (HX) for cooling. The power for the electric motors is produced by generators (SG) connected to the aircraft's engine and APU. After compression and cooling the air is delivered to the cabin.
Technical Solutions

More Electric A320?
Hints (for Today!)
Hints

Get Informed => Personal CO Detector. Get Protected in the Cabin => Breathing Mask

Normal CO Situation

Failure Case: Fume Event


Get CO Detector and Breathing Mask

• The Carbon Monoxide (CO) level in normal operation is much lower than the limit of 50 ppm (specified in CS 25.831). Failure cases did not occur during these measurements.

• We know much CO is present in the cabin during a Fume Event. The elevated CO concentration indicates the severity of the event. Therefore, crew should carry their personal CO detector and be informed and make decisions accordingly!

• If smoke is present, checklists tell pilots to put on their oxygen mask. In such a case, cabin crew should consider wearing a personal breathing mask protecting against nerve gas.

EASA 2017b, p.74

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Hints

Direct Venting of the Cabin in 10000 ft

Direct venting (independently of bleed air) is possible for most passenger aircraft. On the Airbus A320, an emergency ram-air inlet can be opened. These conditions have to be met:

• the altitude of the aircraft is less than 10000 ft,
• the difference between the pressure in the fuselage and the external pressure is less than 70 hPa.

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• the difference between the pressure in the fuselage and the external pressure is less than 70 hPa.
Aircraft Cabin Air  –  Quality or Contamination?

Summary

• **All aviation fluids** can get into aircraft cabin air:
  sucked up from the ground and **ingested into the engine**.

• There are many reasons for odors and contamination, but:
• **Concentrate** on the big issue: **Engine seals leak a small amount of oil by design!**

• **Demand** a **technical change** of the system!

• **Think** about **what you can do today** to make a change. Hints are given!
Aircraft Cabin Air – Quality or Contamination?

Contact

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A List of References is contained in my presentation from 19.09.2017