AIRCRAFT DESIGN AND SYSTEMS GROUP (AERO)

Aircraft Cabin Air & Water Contamination/Quality – An Aircraft Systems Engineering Perspective

Dieter Scholz
Hamburg University of Applied Sciences

QCAQE – Global Cabin Air Quality Executive
SEVENTH ANNUAL FORUM and INFORMATION EXCHANGE
London, 31st March – 2nd April, 2014
Aircraft Cabin Air & Water Contamination/Quality – An Aircraft Systems Engineering Perspective

Contents

• Introduction

• Air and Water – Contamination Hazards

• Aircraft Systems Investigated

• Systematic Solution

• Summary
Aircraft Cabin Air & Water Contamination/Quality – An Aircraft Systems Engineering Perspective

Contents

• Introduction

• Air and Water – Contamination Hazards

• Aircraft Systems Investigated

• Systematic Solution

• Summary
Introduction

**Definition: Aircraft Cabin Air**
A mixture of outside and 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://aircrewhealth.com/Topics/hazards/cabinair.htm

**Definition: Aircraft Systems**
A combination of inter-related items arranged to perform a specific function on an aircraft.

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
Introduction


**Bleed Air Quality:** Requirements should be imposed on the engine manufacturer regarding the quality of the bleed air supplied to occupied compartments.

Under **normal operating conditions:**
The engine bleed air shall be free of engine-generated objectionable odors, irritants, and/or toxic of incapacitating foreign materials.

Following any type of engine ... failure, the engine bleed air shall not contain the above substances to a harmful degree.

... or bleed air systems should incorporate a bleed air cleaner.

**Other Requirements:** FAA Part 25 / CS-25, SAE AIR 1539: Environmental Control System Contamination. Not further discussed here.
Introduction

- water
- food
- radiation
- hydraulic fluid
- bleed air
- systems
- air, combustion products
- air
- gray water
- waste

Think:
- system boundaries
- systems engineering

Dieter Scholz: Aircraft Cabin Air Contamination/Quality – An Aircraft Systems Engineering Perspective

GCAQE Annual Forum
London, 31.03. - 02.04.2014

Aircraft Design and Systems Group (AERO)
Introduction

The question about

Aircraft Cabin Air Contamination

can be related to

Aircraft Potable Water Contamination

Aircraft Water Contamination
can in theory be due to a potable water pressurization system with bleed air.

For this reason an investigation about “cabin air contamination / quality”
should be extended to an investigation about:

• Aircraft Cabin Air and
• Aircraft Potable Water
Contents

• Introduction

• **Air and Water – Contamination Hazards**

• Aircraft Systems Investigated

• Systematic Solution

• Summary
Air, Water, Food – Contamination Hazards and Possibilities

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.

- **Carbon Dioxide**
  Concentrations are generally below FAA regulatory limits.
  Associated with increased perceptions of poor air quality

- **Ozone**
  Elevated concentrations are expected on aircraft without ozone converters.
  Airway irritation and reduced lung function.

- **Pesticides**
  From aircraft “disinsection” with pesticides.

- **Engine Oil**
  Fumes from hot engine oil may enter the cabin via the bleed air system.

- **Deicing Fluid**
  Hazardous substance. Skin sensitizing and irritant.

- **Hydraulic Fluids**
  Frequency of incidents is expected to be relatively low. Mild to severe health effects.

- **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://aircrewwhealth.com/Topics/hazards/cabinair.htm
Air, Water, Food – Contamination Hazards and Possibilities

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.
Aircraft Cabin Air & Water Contamination/Quality – An Aircraft Systems Engineering Perspective

Contents

• Introduction

• Air and Water – Contamination Hazards

• Aircraft Systems Investigated

• Systematic Solution

• Summary
Aircraft Systems Investigated - Major Component Location

737-600/700/800/900 AIRCRAFT MAINTENANCE MANUAL

PNEUMATIC - COMPONENT LOCATIONS

Dieter Scholz: Aircraft Cabin Air Contamination/Quality
– An Aircraft Systems Engineering Perspective
GCAQE Annual Forum
London, 31.03. - 02.04.2014
Aircraft Design and Systems Group (AERO)
Aircraft Systems Investigated - **Bleed Air to Cabin Overview (2)**

- **Outflow Valve**
- **50% Recirculation**
- **50%**

Adapted from FCOM A320
Aircraft Systems Investigated - Air Conditioning Pack (1)
Aircraft Systems Investigated - Air Conditioning Pack (2)

- An Air Cycle Machine (ACM) is a high energy rotor device.
- An ACM may need some form of lubrication (=> oil)
- Lubrication needs will be much smaller than in aircraft engines.
- Use of air bearings is possible.
Aircraft Systems Investigated - Engine Overview

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

K. Aainsqatsi, Wikipedia.org
Aircraft Systems Investigated - Engine Overview

The CFM 56-5-C2 engine is a high bypass ratio turbofan, rated at a 31200 pounds take-off thrust at sea level and flat rated to ISA + 15°C. The engine has a fan air to primary air bypass ratio of 6.6 to 1.

**GENERAL**

- **Low pressure compressor / turbine**
  The low speed rotor (N1) consists of a front fan (single stage) and a four-stage LP compressor connected to a five-stage LP turbine.

- **High pressure compressor / turbine**
  The high speed rotor (N2) consists of a nine-stage high pressure compressor connected to a single-stage HP turbine.

- **Combustion chamber**
  The combustion chamber is annular and fitted with 20 fuel nozzles and 2 igniters.

- **Accessory gearbox**
  The accessory gearbox, located at the bottom of the fan case, receives torque from horizontal HP rotor drive shaft and drives gearbox mounted accessories such as : IDG, hydraulic pump, oil pump, engine driven pump, HMU and electrical generator for the FADEC.
Aircraft Systems Investigated - Engine Overview

A320 Training Manual: CFM 56-5
Aircraft Systems Investigated - Engine Overview

RR Trent 900
Aircraft Systems Investigated - Labyrinth Seal

Positive air pressure and flow against the oil pressure should prevent the seals from leaking.

The CAA has already taken remedial action to help operators of particular aircraft reduce the incidence of fume events e.g. engine oil servicing procedures and engine sealing modifications.

Aircraft Systems Investigated - Engine Air and Oil System

FCOM A340: Engine Air System

FCOM A340: Engine Oil System
Aircraft Systems Investigated - Engine Air and Oil System

Deaerator:
A chamber in the lubrication system of a gas turbine engine in which the return oil from the engine collects before it is returned to the reservoir. Any air in the oil is allowed to escape while the oil is in this chamber.
Aircraft Systems Investigated - Engine Air and Oil System

Quotes from: Exxon Mobile: “Jet Engine Oil System” with remarks:

- “The scavenged oil flow is slightly lower than the supply flow due to normal oil consumption through the deoiler, oil seals, and oil leaks.” (I.e.: Oil escapes also from the seals)
- “Therefore, a large amount of air is carried by the scavenge oil and must be removed through a de-aerator when entering the tank.” (I.e.: Seals do not seal but allow large amounts of air to enter the seals. If pressure in the compressor is less than pressure in the oil system, oil can escape from the seals.)

Aircraft Systems Investigated - APU - Overview

APU BLEED VALVE

LOAD 2 STAGES COMPRESSOR

3 STAGES TURBINE

APU GEN

OIL PUMP

GEAR BOX

STARTER

FLAP MOTOR

COMBUSTION CHAMBER

FUEL SUPPLY

FCOM A340: APU Description
Aircraft Systems Investigated - APU - Overview

GENFAM LHT B737 APU AlliedSignal 131-9B
Aircraft Systems Investigated - **APU with Bearings and Load Compressor**

- An **Auxiliary Power Unit (APU)** is a gas turbine engine.
- An APU will need some form of lubrication (=> oil)
- Lubrication needs will be smaller than in aircraft engines.

GENFAM A320 APU GTCP36-300
Aircraft Systems Investigated - APU with Bearings - Enlargements

- seal
- rotating shaft
- inner bearing ring
- ball from ball bearing
- outer bearing ring

GENFAM A320 APU GTCP36-300
Aircraft Systems Investigated - Cabin Air Distribution

GENFAM A320: Cabin Air Distribution
Aircraft Systems Investigated - Potable Water System
Aircraft Systems Investigated - Potable Water System

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.
Aircraft Systems Investigated - Potable Water Tank Pressurization

Training Material A320: Potable Water System pressurization.
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 - 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.
Aircraft Systems Investigated - Hydraulic Reservoir Pressurization

Reservoir Pressurization Manifold

GenFam, A320
Aircraft Systems Investigated - **Bleedless B787**

- ECS
- SG
- P
- M
- XFR
- APU
- HX
- NGS
- CTAI
- Battery
- Engine
- RAT
- P
- M

**Dieter Scholz: Aircraft Cabin Air Contamination/Quality – An Aircraft Systems Engineering Perspective**

**Boeing: AERO**

**GCAQE Annual Forum**
London, 31.03. - 02.04.2014

**Aircraft Design and Systems Group (AERO)**

01.04.2014, Slide 38
Aircraft Cabin Air & Water Contamination/Quality – An Aircraft Systems Engineering Perspective

Contents

- Introduction
- Air and Water – Contamination Hazards
- Aircraft Systems Investigated
- Systematic Solution
- Summary
Systematic Solution – Long Term Exposure

- Starting point: Illness of known crew and passenger.
- Illness caused by cabin air is hard to prove (only one person successful so far)
  ⇒ New approach necessary

- Prove oil contains highly dangerous substances for humans ✓
- Estimate amount of oil that gets into the cabin:
  - Determine engines oil consumption per flight hour (airline maintenance records): \( C \)
  - Estimate ratio of oil out of all seals versus the total oil out (also leaving the deaerator): \( x_{oil} \)
  - Determine number of all bearings or seals: \( n_b \)
  - Determine number of bearings or seals upstream of first bleed port: \( n_{b,up} \)
  - Calculate „upstream“ bearing ratio: \( x_{b,up} = n_{b,up} / n_b \)
  - Estimate engine mass flow: \( \frac{dm_e}{dt} = S_e \cdot v \cdot \rho_{air} \) \( S_e \): engine frontal area, \( v \): aircraft speed
  - Estimate bleed flow into cabin: \( \frac{dm_b}{dt} = \frac{dV_{pax}}{dt} \cdot n_{pax} \cdot \rho_{air,cab} \)
  - Calculate oil in cabin per flight hour:
    \[
    C_{cab} = C \cdot x_{oil} \cdot x_{b,up} \cdot \frac{dm_b}{dt} / \left[ \frac{dm_e}{dt} \cdot \frac{1}{(BPR+1)} \right]
    \]
Systematic Solution – Short Term Exposure: Fume Event

There are very few passenger complaints about health issues to airlines or the authorities. CAA figures from 2011 that written complaints in the 10 years from January 2001, 244 were categorised as medical. The main health problems raised were pregnancy issues; skiing injuries; infectious diseases; allergies (typically from peanuts); food poisoning and passengers being scalded by coffee/tea.


Passenger numbers at UK airports to increase from 219 million passengers in 2011 to …


Probability calculation assuming:
- 219 million passengers also in the years from 2001 to 2011.
- Each flight lasts 1 FH

\[ P(\text{health issue}) = \frac{244}{219000000} \approx 1 \cdot 10^{-6} \text{ allowed would be } 10^{-5} \ldots 10^{-7} \text{ (overleaf)} \]

If all reported health issues together would be caused by technical grounds it would still be acceptable!
### Systematic Solution – Short Term Exposure: Fume Event

<table>
<thead>
<tr>
<th>effect on aircraft and occupants</th>
<th>normal</th>
<th>nuisance</th>
<th>operating limitations</th>
<th>significant reduction in safety margins</th>
<th>large reduction in safety margins</th>
<th>multiple deaths, usually with loss of aircraft</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>emergency procedures</td>
<td>difficult for crew to cope with adverse conditions</td>
<td>crew extended because of workload or environmental conditions</td>
<td>serious injury or death of small number of occupants</td>
</tr>
<tr>
<td>passenger injuries</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>category of effect</th>
<th>minor</th>
<th>minor</th>
<th>minor</th>
<th>major</th>
<th>hazardous</th>
<th>catastrophe</th>
</tr>
</thead>
<tbody>
<tr>
<td>probability of a failure according to JAR 25 (per flight hour)</td>
<td>frequent</td>
<td>frequent</td>
<td>reasonably probable</td>
<td>remote</td>
<td>extremely remote</td>
<td>extremely improbable</td>
</tr>
<tr>
<td></td>
<td>$10^0 \ldots 10^{-2}$</td>
<td>$10^{-2} \ldots 10^{-3}$</td>
<td>$10^3 \ldots 10^5$</td>
<td>$10^{-5} \ldots 10^{-7}$</td>
<td>$10^{-7} \ldots 10^{-8}$</td>
<td>$&lt; 10^{-9}$</td>
</tr>
</tbody>
</table>
Aircraft Cabin Air & Water Contamination/Quality – An Aircraft Systems Engineering Perspective

Contents

• Introduction

• Air and Water – Contamination Hazards

• Aircraft Systems Investigated

• Solution Systematic

• Summary
Summary

Look for oil contamination in all rotating machinery:
- engine,
- APU,
- Air Cycle Machine (ACM),
- electrical compressor (B787 has air bearings)

Look for all possible paths on which oil can get in contact with people on board.

Today most engine oil contains harmful substances. As long as this is the case it has nothing to do in the aircraft when only the slightest chance exist these substances get in contact with people (air, water, …)

Argue as simple as possible!
Aircraft Cabin Air & Water Contamination/Quality – An Aircraft Systems Engineering Perspective

Contact

info@ProfScholz.de

http://www.ProfScholz.de