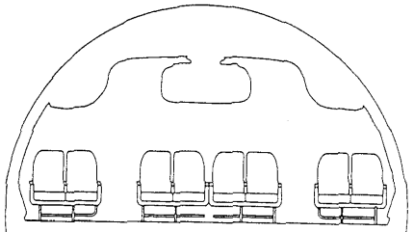
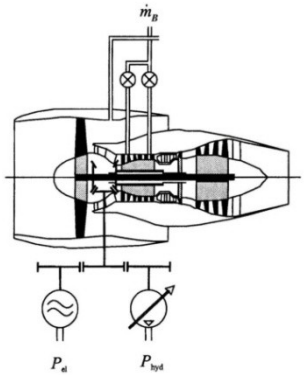
Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

AIRCRAFT DESIGN AND SYSTEMS GROUP (AERO)

Aircraft Cabin Air – Quality or Contamination?





Dieter Scholz Hamburg University of Applied Sciences

Personalversammlung "Kabine", Deutsche Lufthansa AG

Frankfurt, 20. November 2017

Contents

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://aircrewhealth.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

Introduction

Health Effects: **Occupational Health & Flight Safety**

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

- **Long-term heath effects**:
  - to passengers
  - to crew => **occupational health** (OH) **=> CS 25.831**
    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

    => CS 25.1309

(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://aircrewhealth.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

Potential sources ... *of air contamination*	Potential impact
Engine start during push back	Exhaust gases (e.g., CO, CO_2, NO_X, fuel, particles)
Bleed air switch off during engine start	Short time increase of CO_2
Cabin cleaning in general **Interior cleaning**	VOC, e.g. alcohols, flavors (terpenes), aldehydes Residual of tetrachloroethene
No ozone converters installed	Ozone, particularly in cruise
De-icing fluids	1,2-Propanediol (major constituent) and various additives (e.g., dyes, thickener, antioxidants)
Aircraft traffic at the airport	Exhaust gases (e.g., CO, CO_2, NO_X, fuel, particles)
Car traffic at the airport	Exhaust gases (e.g., CO, CO_2, NO_X, gasoline, particles)
Passengers	Emission of CO_2, various VOCs, offensive smell
Restrooms	Smell, VOC from cleaning products
Furnishings	VOC/SVOC, particulate organic matter (POM), flame retardants e.g. organophosphates
Maintenance	Various VOCs, lubricants
Lubricants	Oil base stock, organophosphates, POM
Hydraulic fluids	e.g. Tributyl phosphate (TBP), triphenyl phosphate (TPP)
Engine oils	Tricresyl phosphate (TCP), trixylyl phosphate (TXP), Amines
In case of thermal degradation	VOCs, organic acids, aldehydes, CO, CO_2, potential unknown products

only considered here is:

(EASA 2017b)

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**.

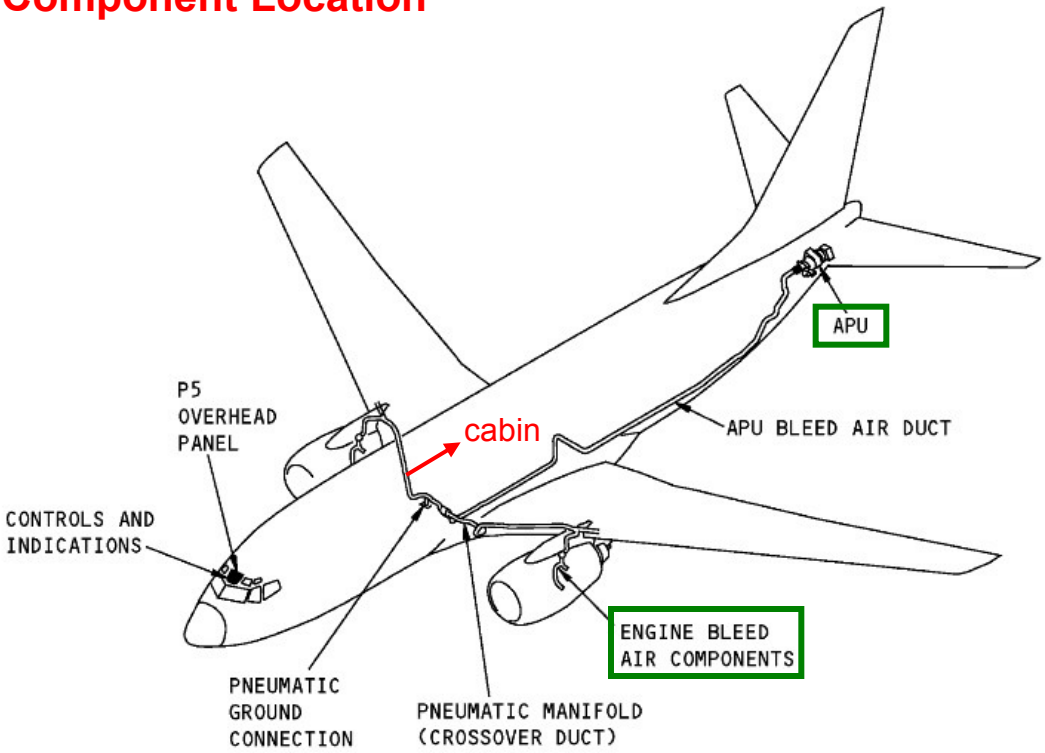
See also: https://youtu.be/p5l3fD2WIQc

Engine Oil => Cabin Air? Yes

Air Conditioning Technology

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

Major Component Location

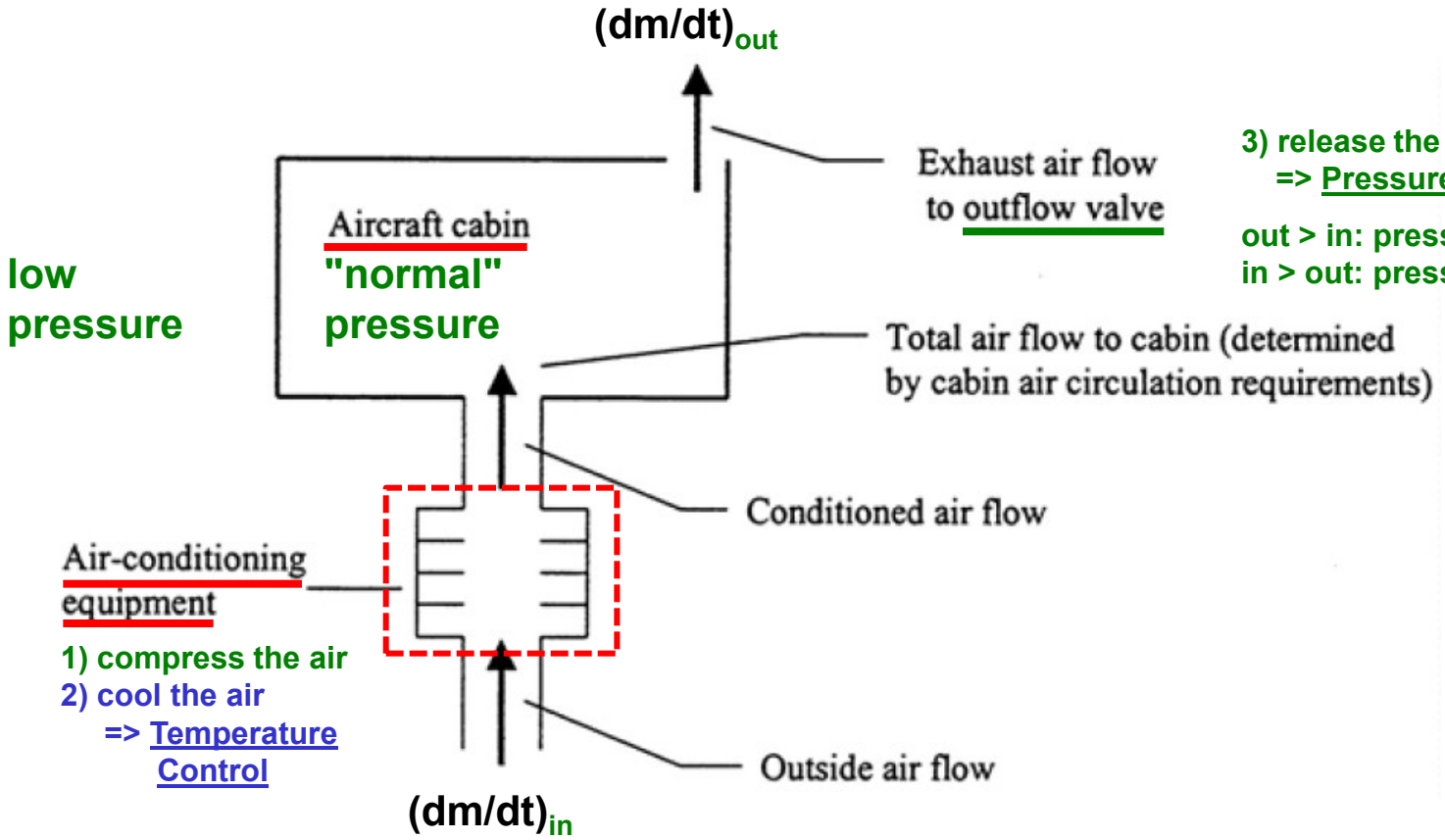


PNEUMATIC - COMPONENT LOCATIONS

Adapted from (AMM B737)

Air Conditioning Basics

Temperature Control, Pressure Control, Ventilation

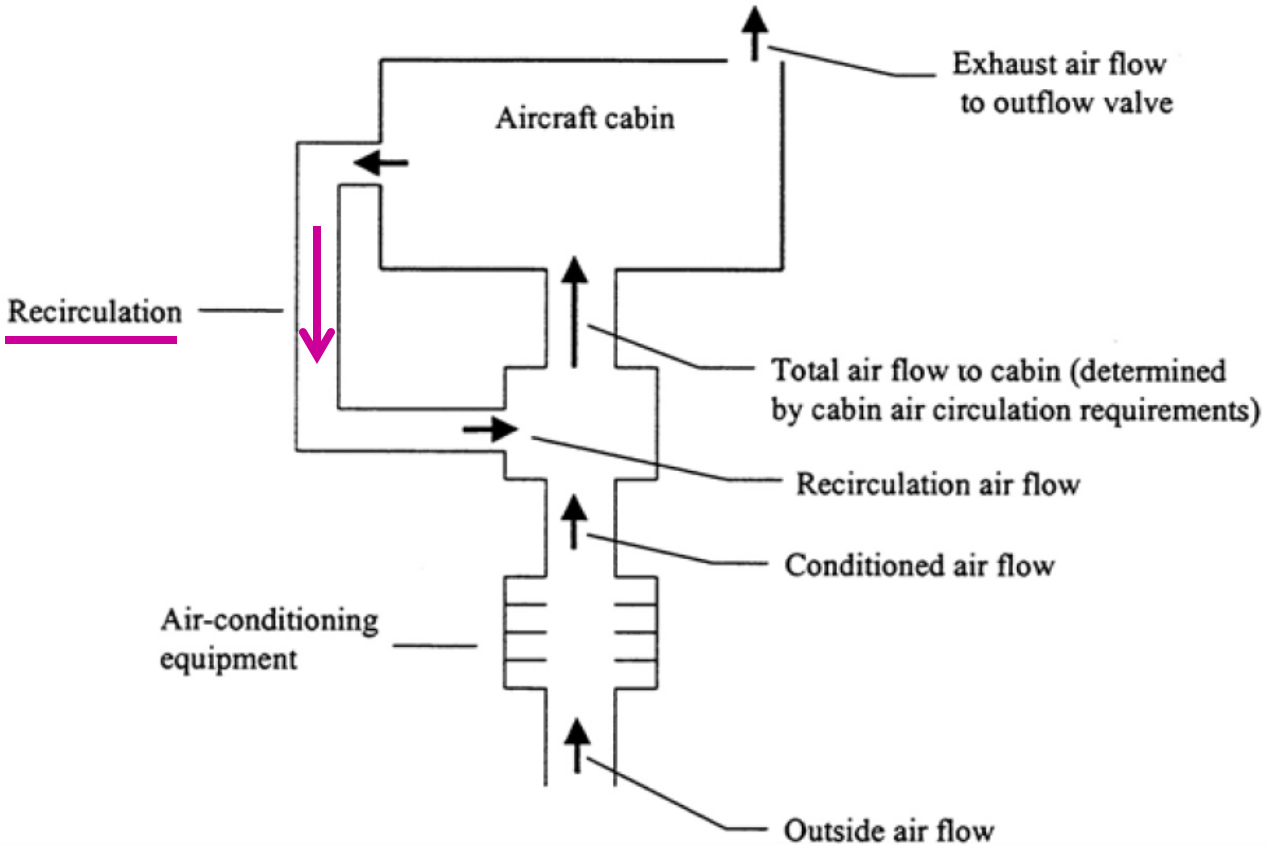


3) release the air
=> Pressure Control:

out > in: pressure goes down
in > out: pressure goes up

Adapted from (NRC 2002)

Air Conditioning with Recirculation



Adapted from (NRC 2002)

Air Conditioning Technology

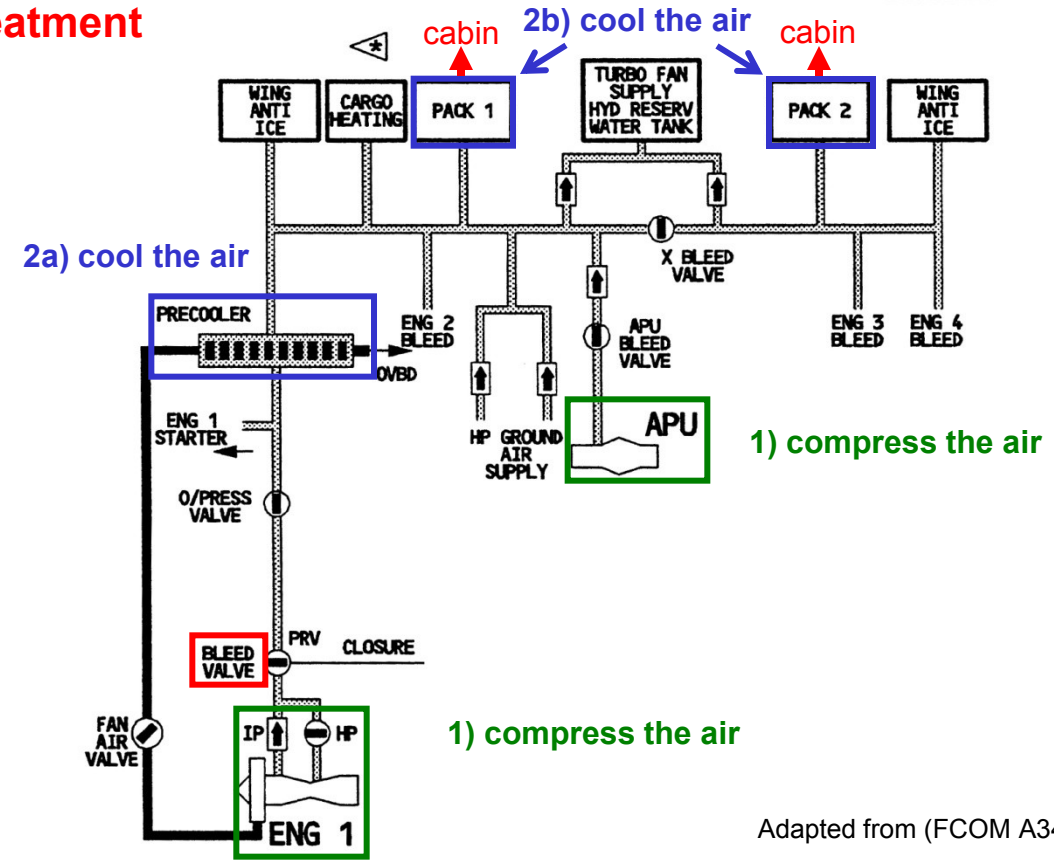
A340 FLIGHT CREW OPERATING MANUAL	PNEUMATIC DESCRIPTION	1.36.10	P 3
		REV 05	SEQ 001

FOR INFO

"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

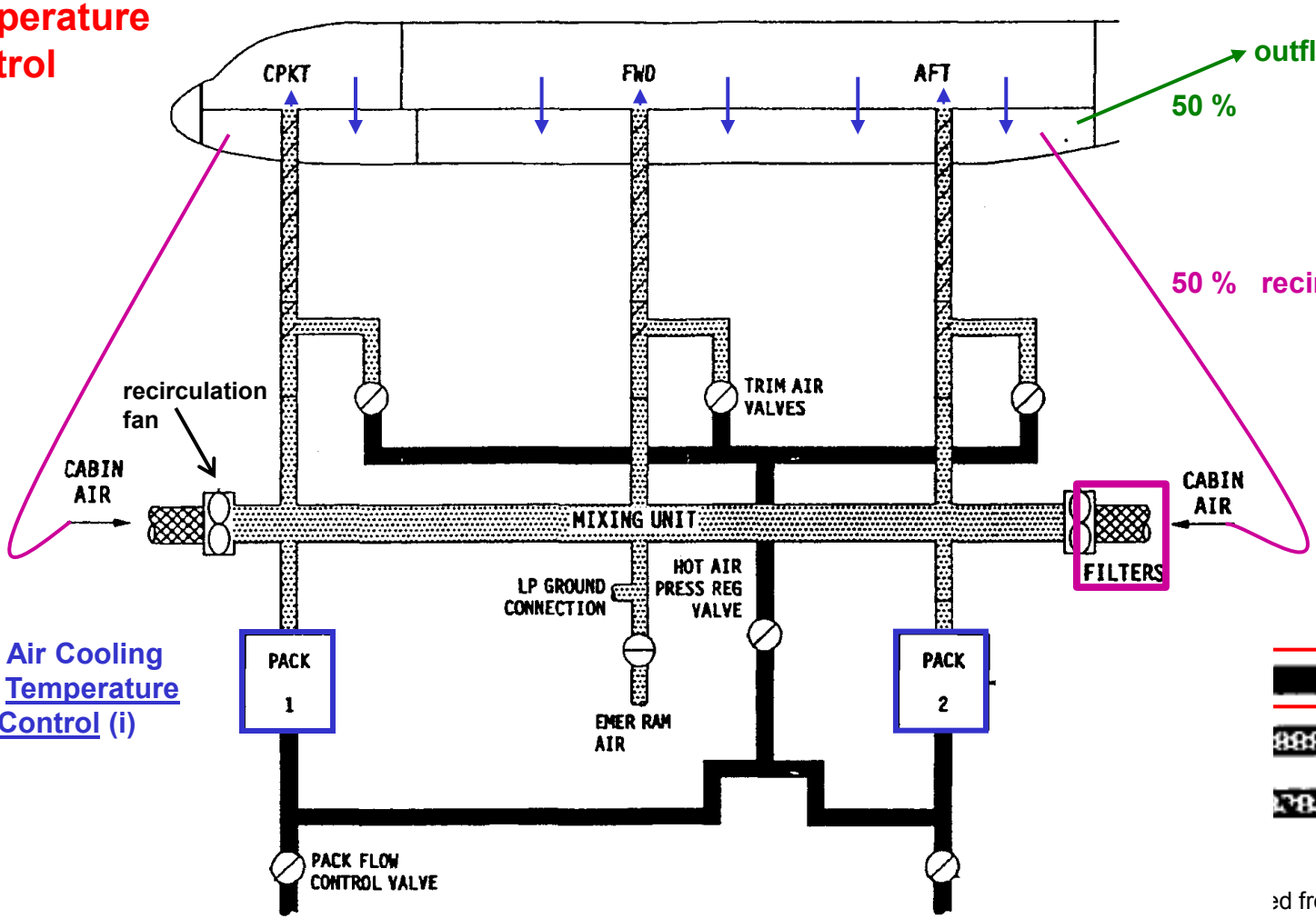


Adapted from (FCOM A340)

Air Conditioning Technology

A320

Temperature Control

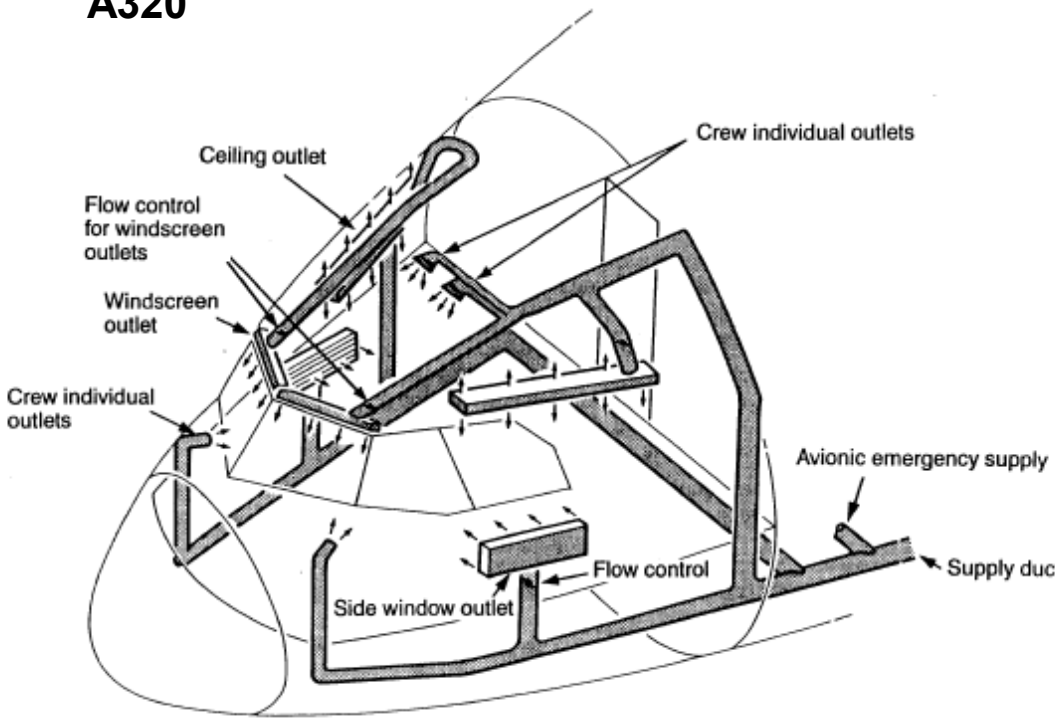


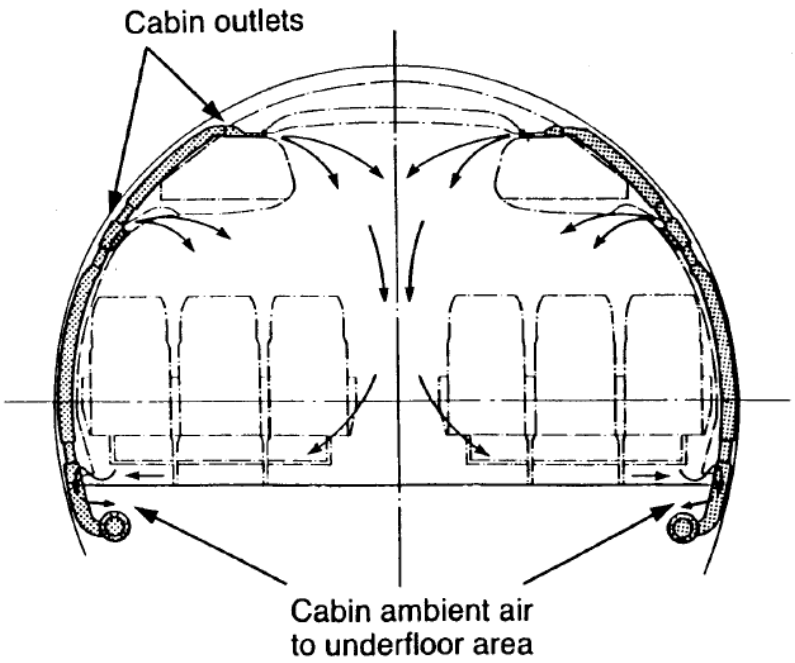
2b) Air Cooling
Temperature Control (i)

ed from (FCOM A320)

Cabin Air Distribution

A320

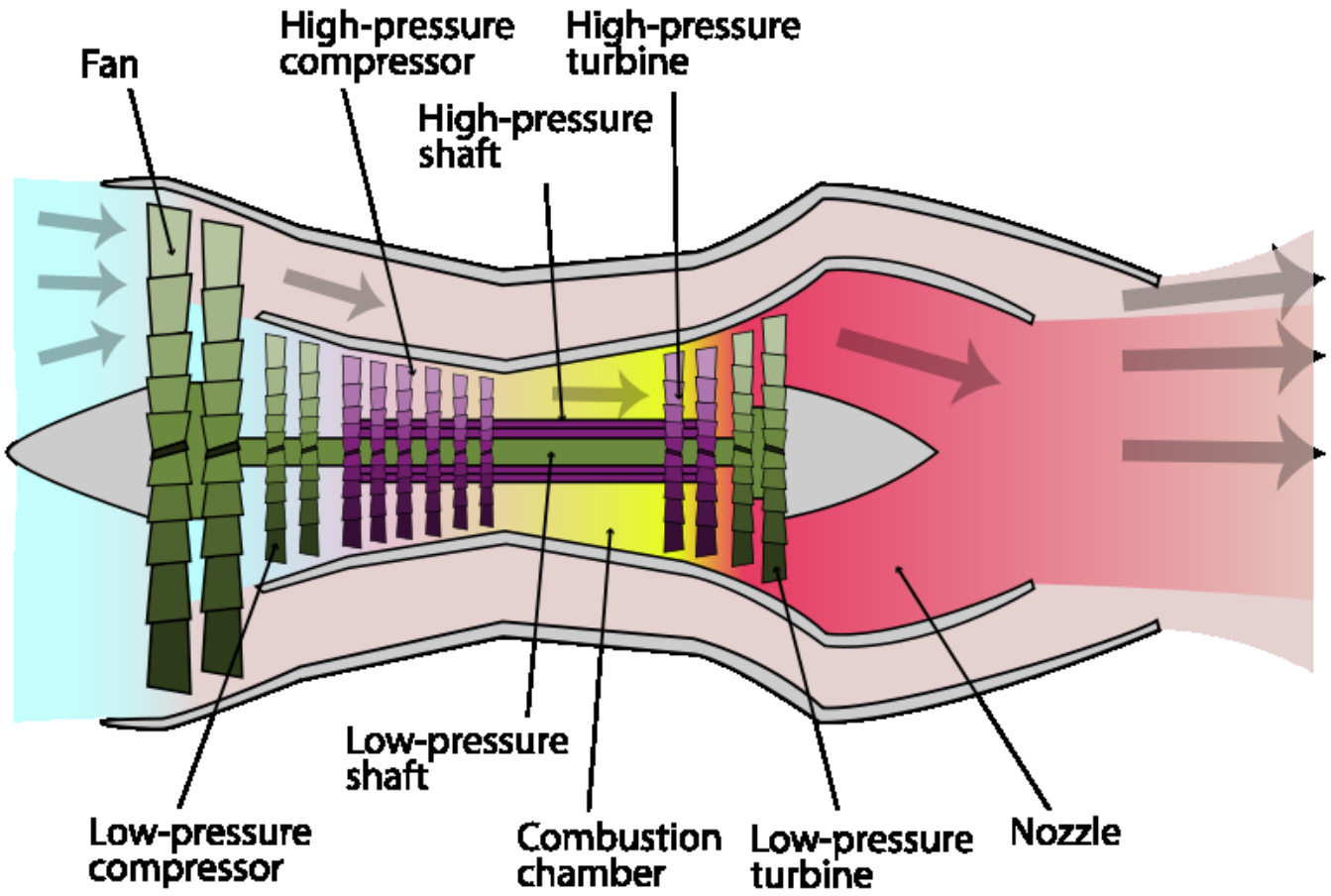




(GENFAM A320)

Jet Engine

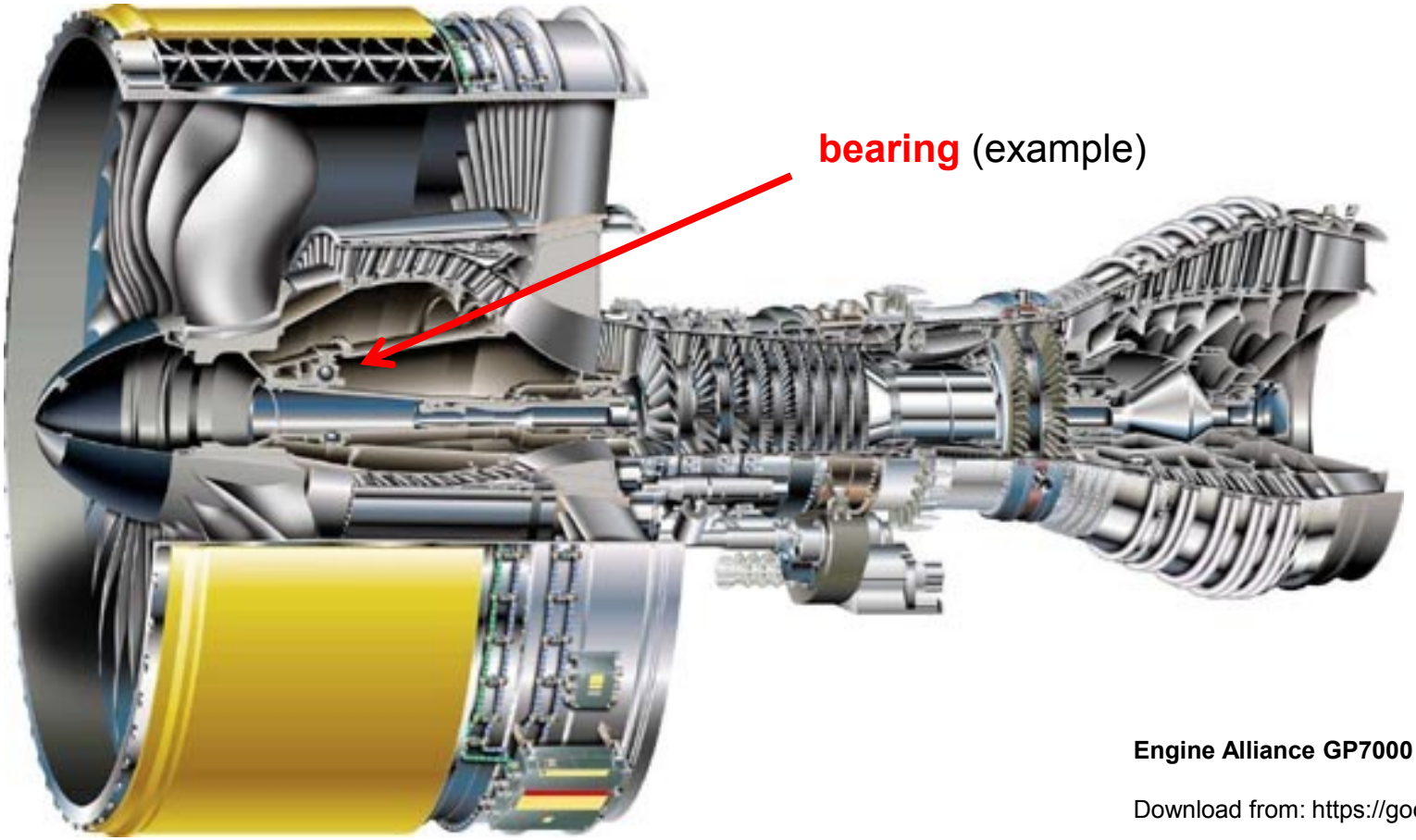
Engine Overview



K. Aainsqatsi
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

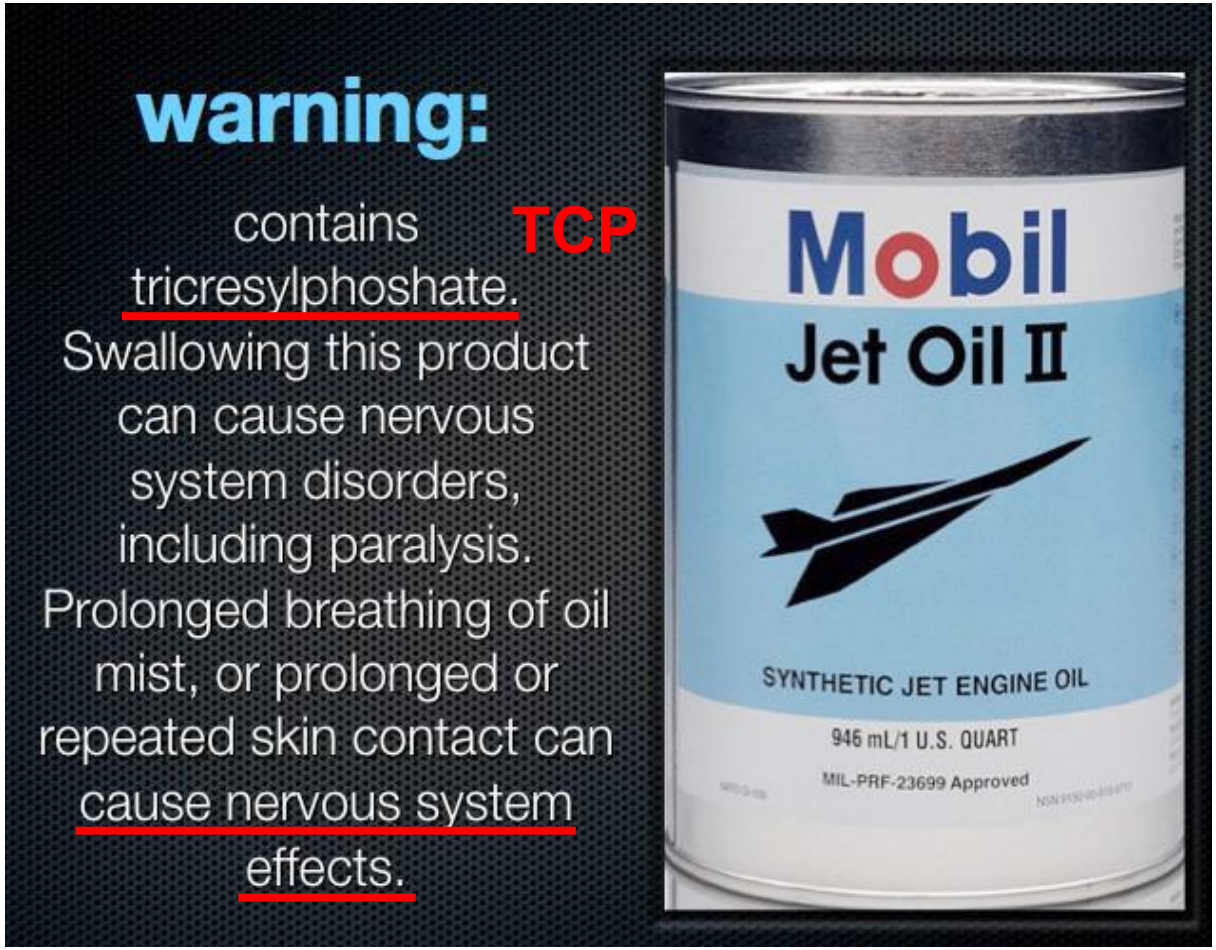
Jet Engine

Jet Engine Bearing

(Exxon 2016b)

Jet Engine

Judging Jet Engine Oil Based on Warnings Given by Manufacturer



ExxonMobil

(Cannon 2016)

How much Oil Gets into the Cabin?

Health Effects? => EASA Study 2017: AVOIL

AVOIL – Characterisation of the toxicity of aviation turbine engine oils after pyrolysis (EASA 2017a)

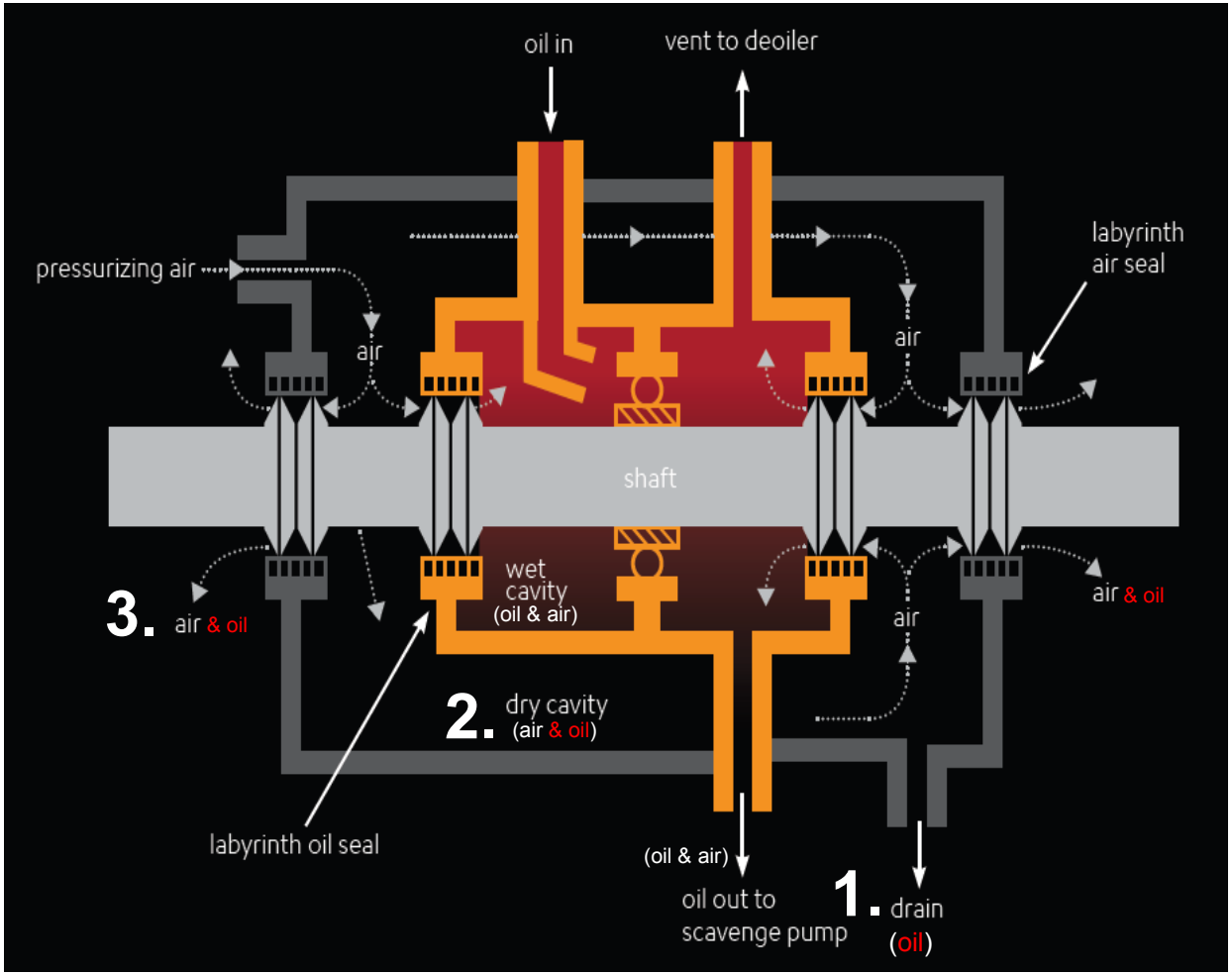
"a ... list of 127 compounds [VOC] was ... identified ... ". The hazard profile is given in Appendix 6:

Compound #	Name	CAS	Harmonized classification	Self-classification*
1	Diethyl Phthalate	84-66-2		NC
2	1-Nonene, 4,6,8-trimethyl-	54410-98-9		
3	2-Ethylhexyl salicylate	118-60-5		Skin Irrit. 2
4	Acetophenone	98-86-2	Acute Tox. 4 Eye Irrit. 2	
5	Benzaldehyde	100-52-7	Acute Tox. 4	
6	Benzene, 1,3-bis(1,1-dimethylethyl)-	1014-60-4	NR	NR
7	Heptane, 4-methyl-	589-53-7	Asp. Tox. 1 Skin Irrit. 2 STOT SE 3	
8	Nonanal	124-19-6		NC
9	2,4-Dimethyl-1-heptene	19549-87-2		Asp. Tox. 1
...	...	...	...	...
124	Isopropyl Myristate	110-27-0		NC
125	Tetradecanoic acid	544-63-8		NC
126	1-Pentene, 4-methyl-	691-37-2		Asp. Tox. 1 Or Skin Irrit. 2 Eye Irrit. 2 STOT SE 3
127	2-Cyclopenten-1-one	930-30-3		NC

* 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**.

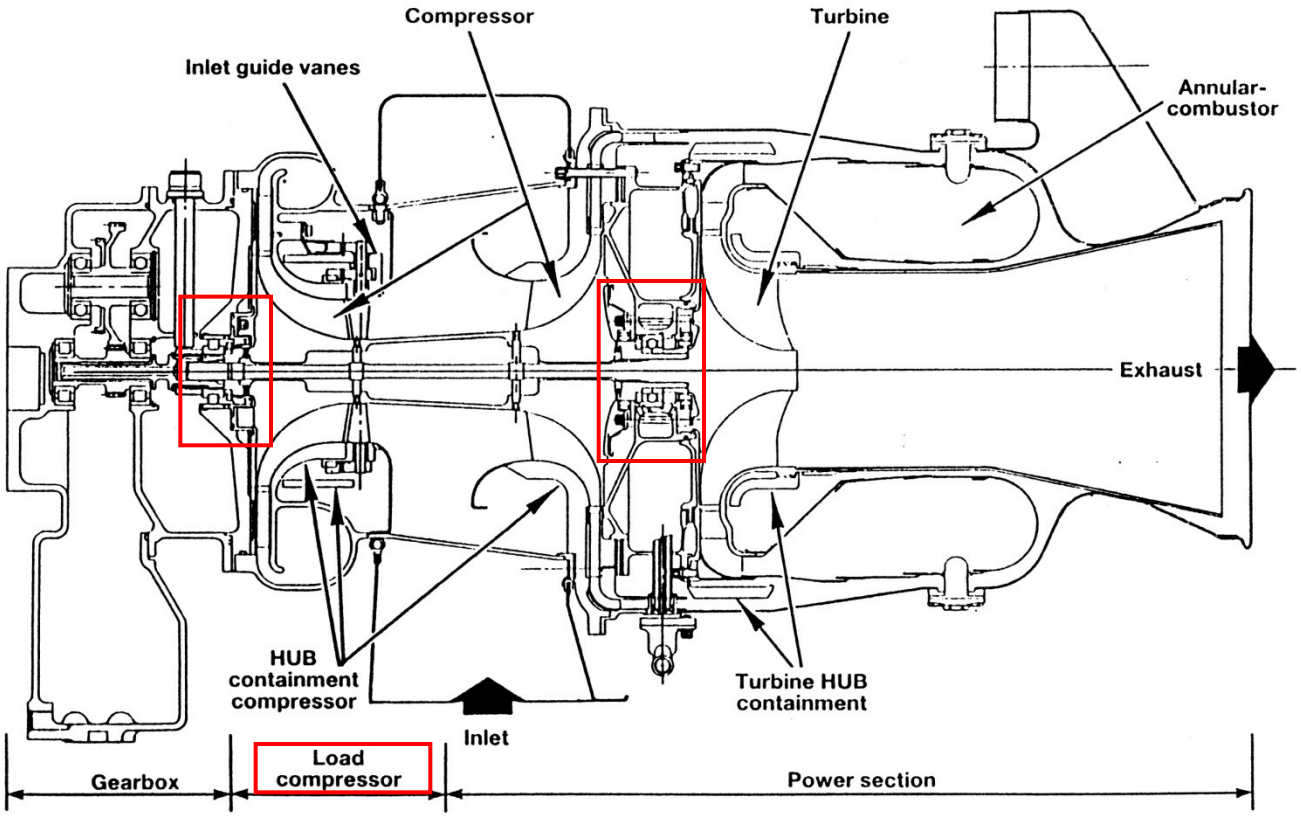
=> **Engines leak small amounts of oil by design!**

based on:
Exxon 2016b

Auxiliary Power Unit (APU)

Bearings and Load Compressor

APU GTCP36-300



(GENFAM A320)

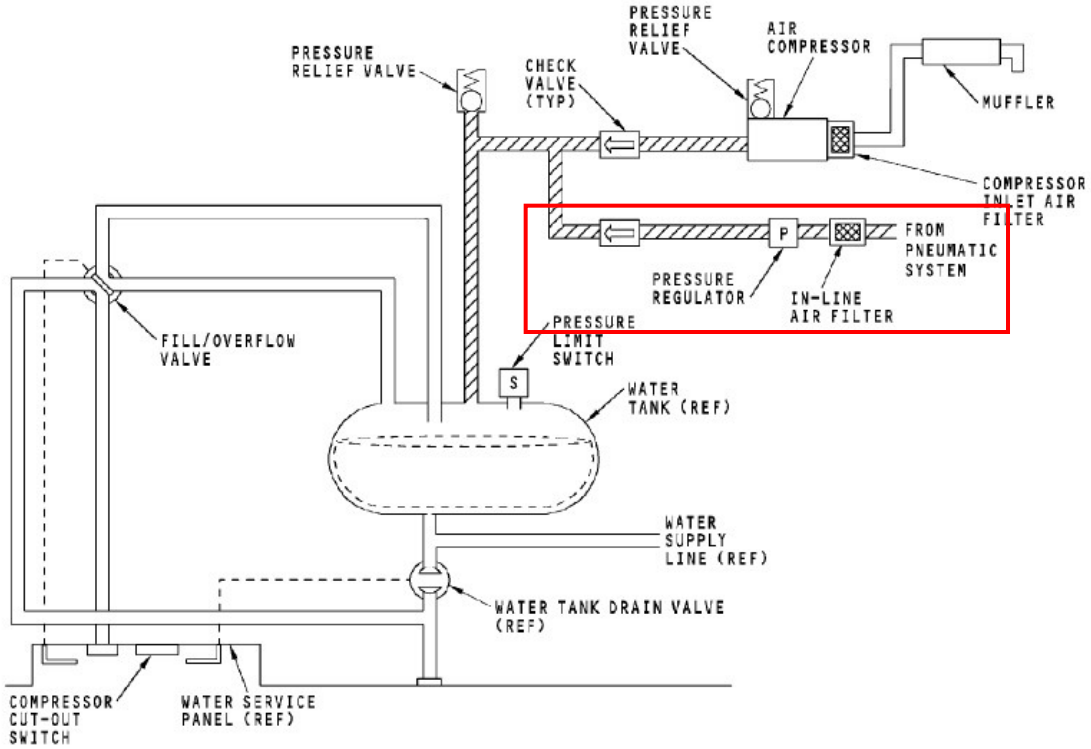
- An Auxiliary Power Unit (APU) is a gas turbine engine.
- An APU will need some form of lubrication (e.i. oil).
- Lubrication needs will be smaller than in aircraft engines, but the APU otherwise experiences the same problems with oil leakage as described for the engine.

Engine Oil => Water? Yes

Aircraft Systems Investigated - Potable Water Tank Pressurization

BOEING

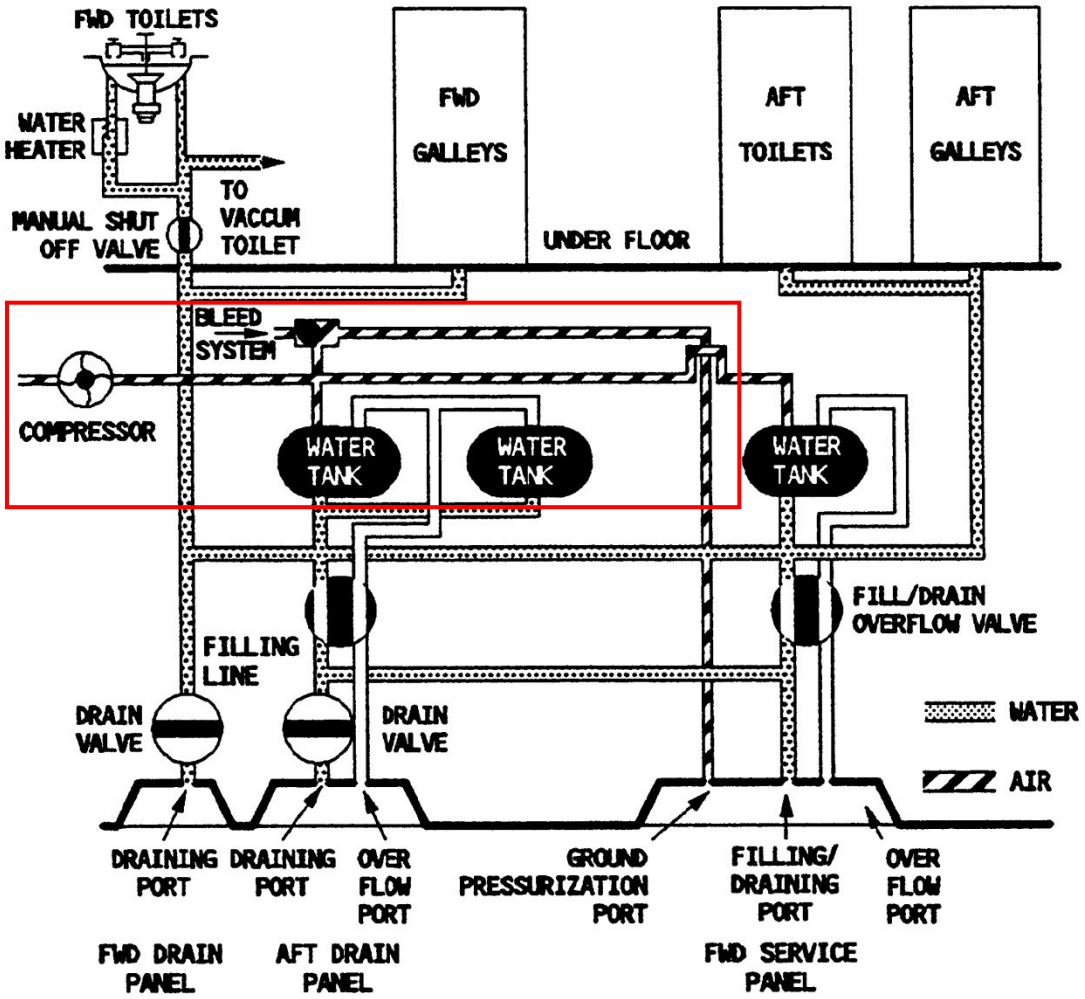
737-600/700/800/900 AIRCRAFT MAINTENANCE MANUAL



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

WATER/WASTE - WATER TANK PRESSURIZATION - FUNCTIONAL DESCRIPTION

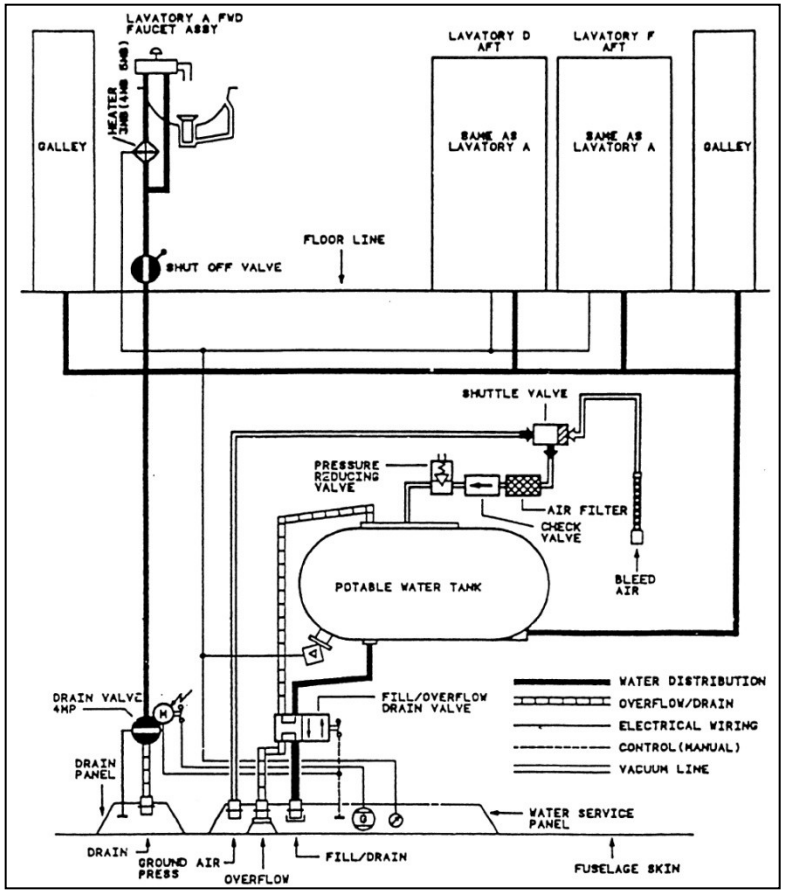
Aircraft Systems Investigated - Potable Water Tank Pressurization

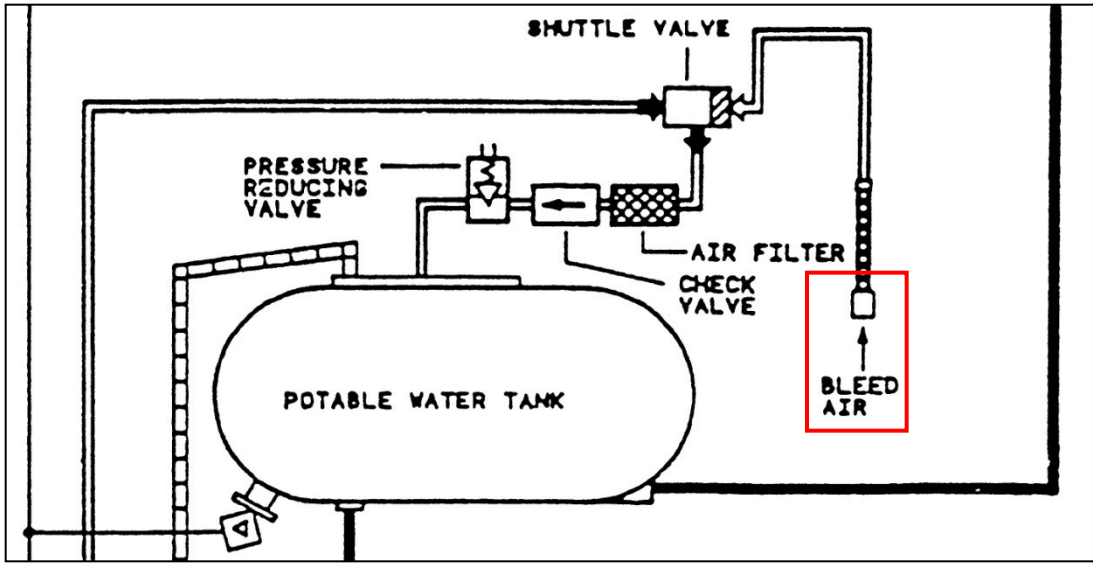


- Possible bleed air contaminations could reach the potable water.

FCOM **A340**: Potable Water System Description

Aircraft Systems Investigated - Potable Water Tank Pressurization





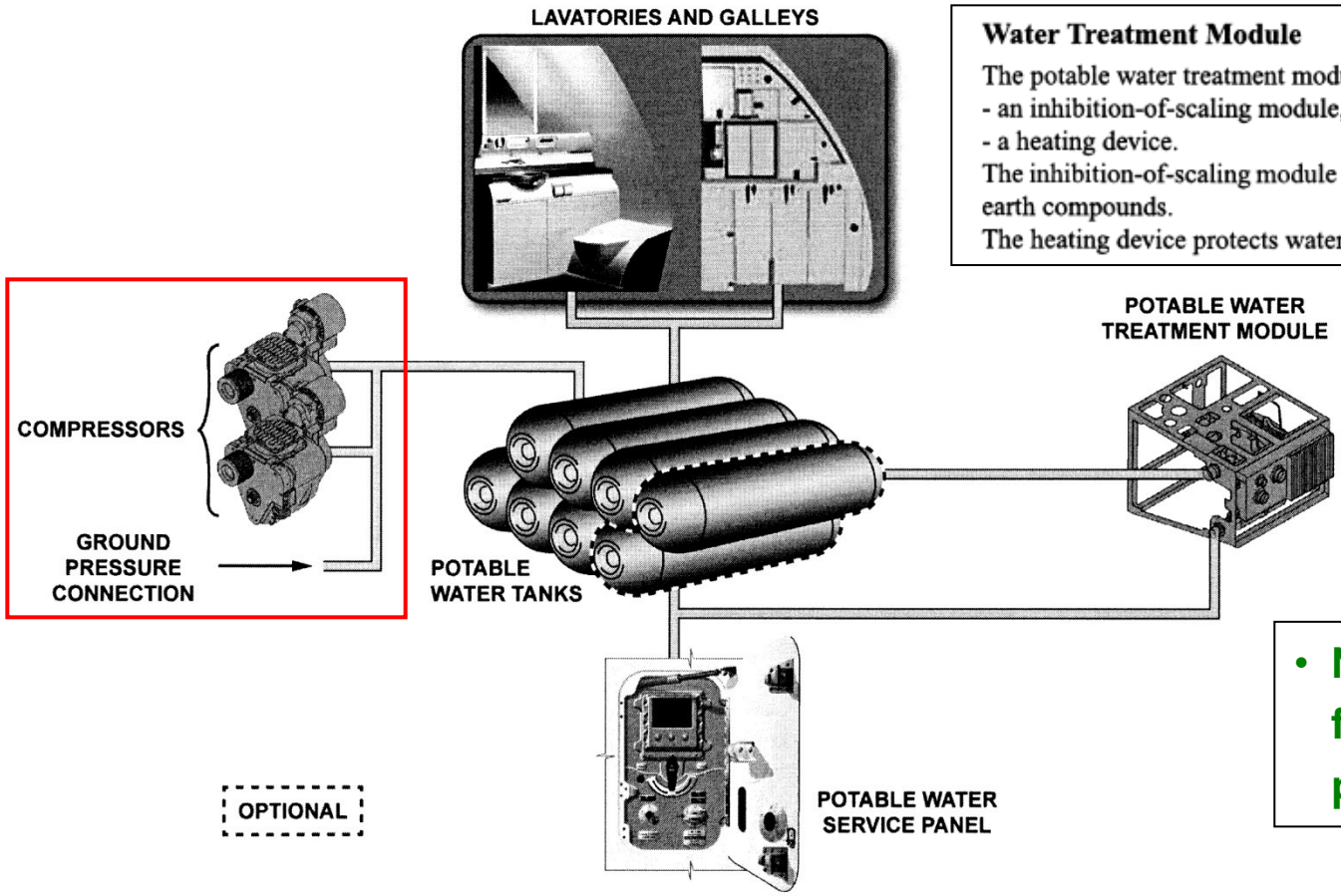
Training Material **A320**: Potable Water System pressurization.

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

Aircraft Systems Investigated - Potable Water System

AIRBUS
Training & Flight Operations Support and Services

A380 TECHNICAL TRAINING MANUAL



Water Treatment Module

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

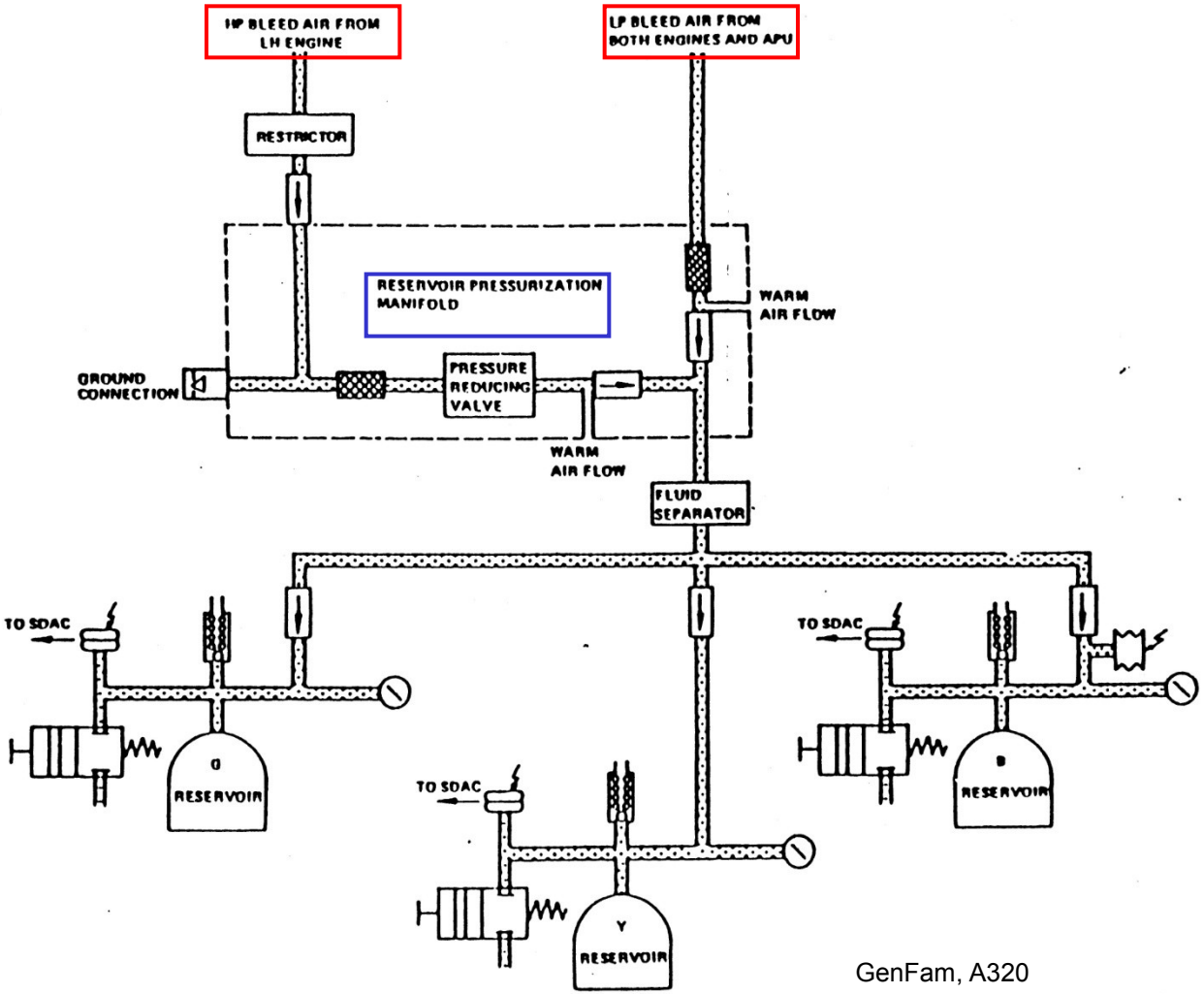
The inhibition-of-scaling module avoids forming of layers of alkaline earth compounds.
The heating device protects water against freezing.

- **No bleed air used for potable water pressurization**

A380

Hydraulic Fluid => Cabin Air / Water? No

Aircraft Systems Investigated - Hydraulic Reservoir Pressurization



GenFam, A320

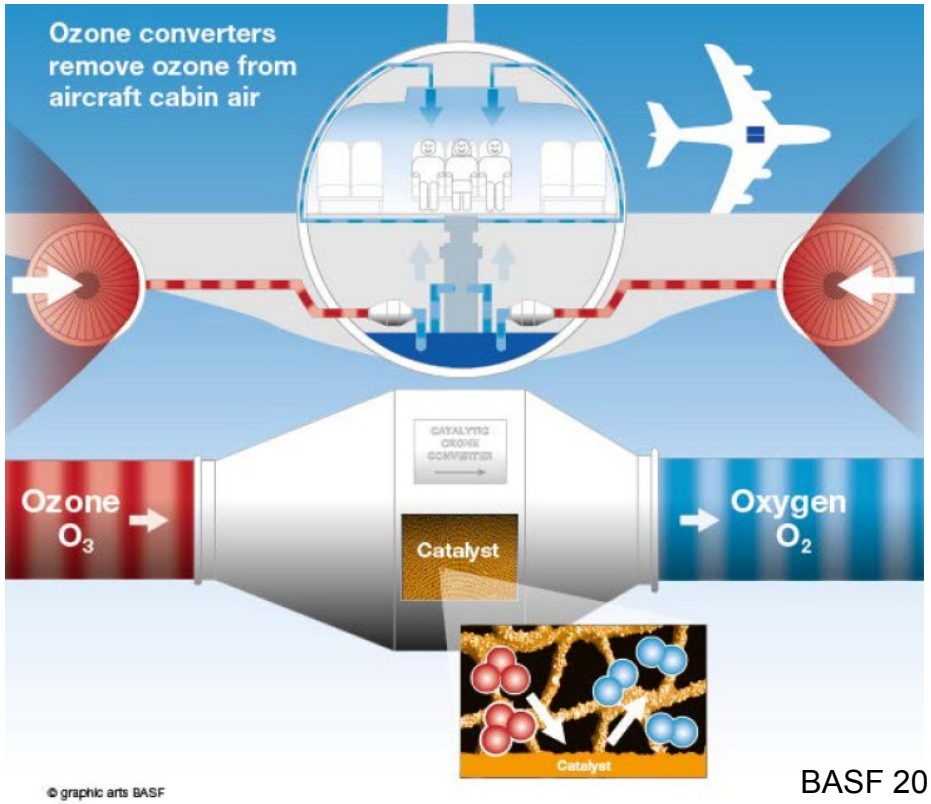
- Hydraulic reservoirs are connected via bleed lines with the potable water tanks.
- Pressurized air is in free contact with the hydraulic fluid surface.
- In flight, hydraulic fluid would need to flow upstream and opposite sense through two check valves to get into the bleed line.
- On the ground, contaminated 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.**



BASF 2014
https://www.basf.com/en/company/news-and-media/news-releases/2014/06/p-14-265.html

Technical Solutions

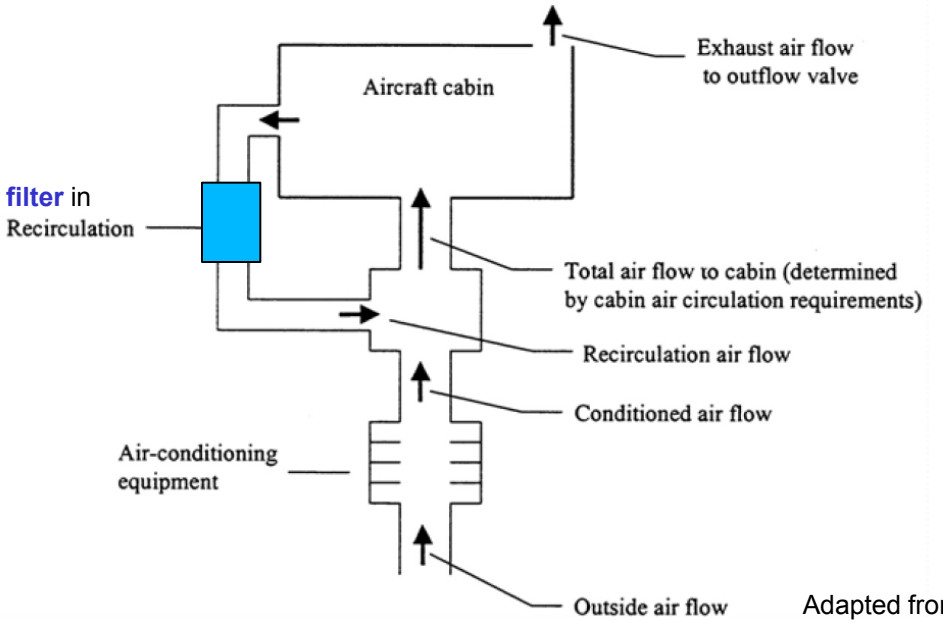
Filter in the Recirculation Path

Pall offers Odour/VOC Removal Filters

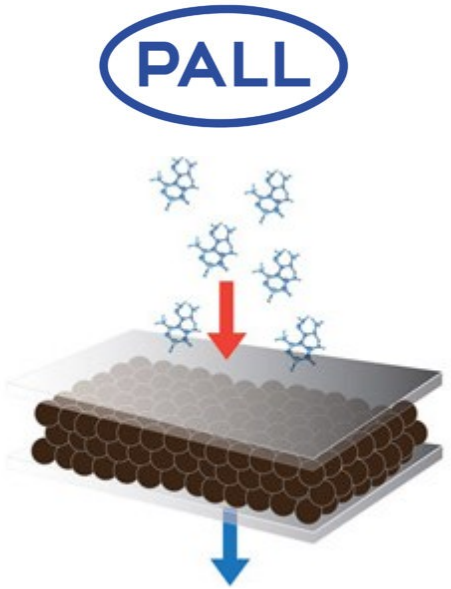
- "The carbon adsorbent is effective at adsorbing volatile organic compounds (VOC). Test results have shown a removal efficiency of 65% ... 73% when challenged with TCPs in the gaseous phase." (Pall 2011)

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 recirclulation path of the cabin air.



Adapted from (NRC 2002)



Schematic of carbon filter (Pall 2011)

(Lufthansa 2017)

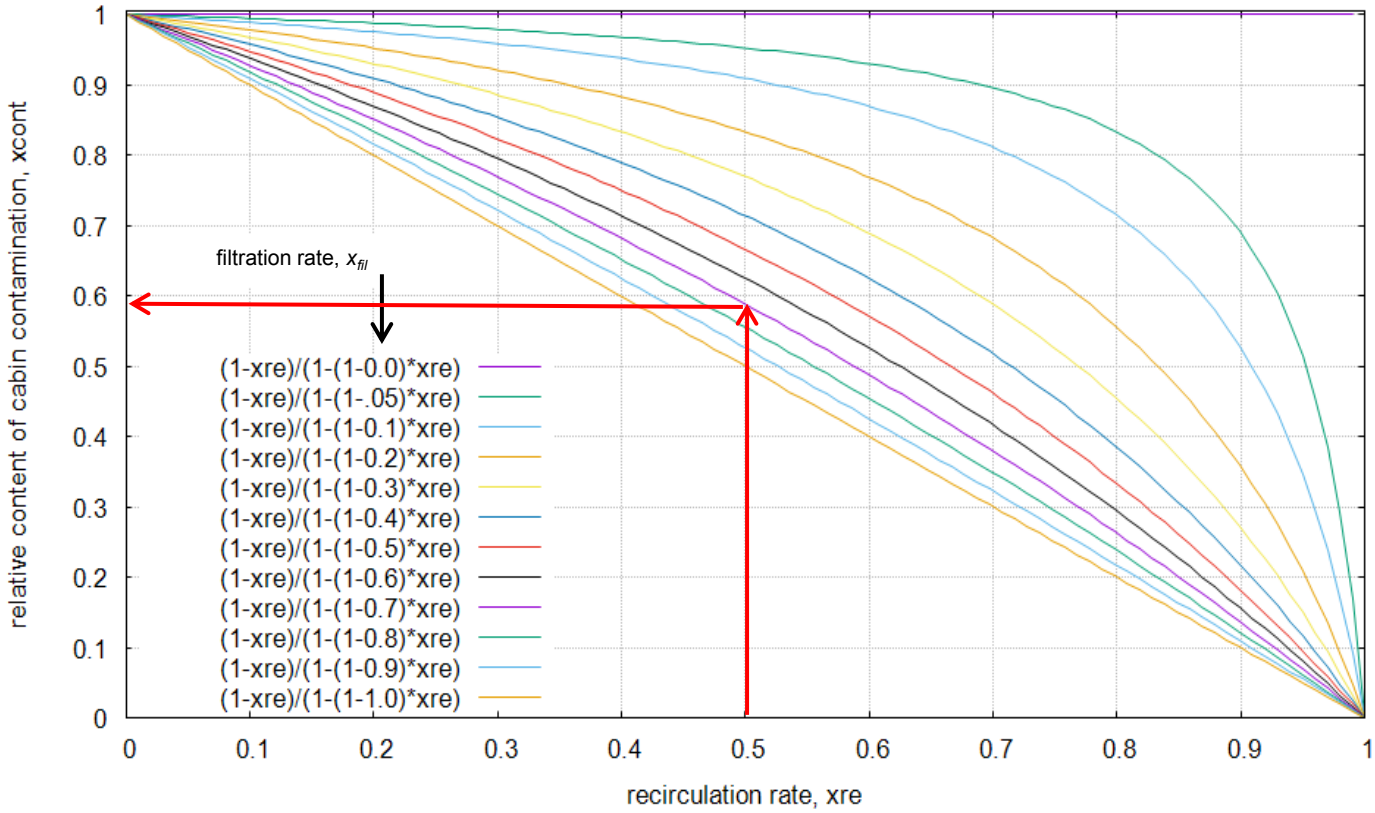
Technical Solutions

Efficiency of Filter in the Recirculation Path

$$\frac{x_{cont,cab}}{x_{cont,in}} = \frac{1 - x_{re}}{1 - \left(1 - x_{fil}\right) x_{re}}$$

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 ≈ 60% .

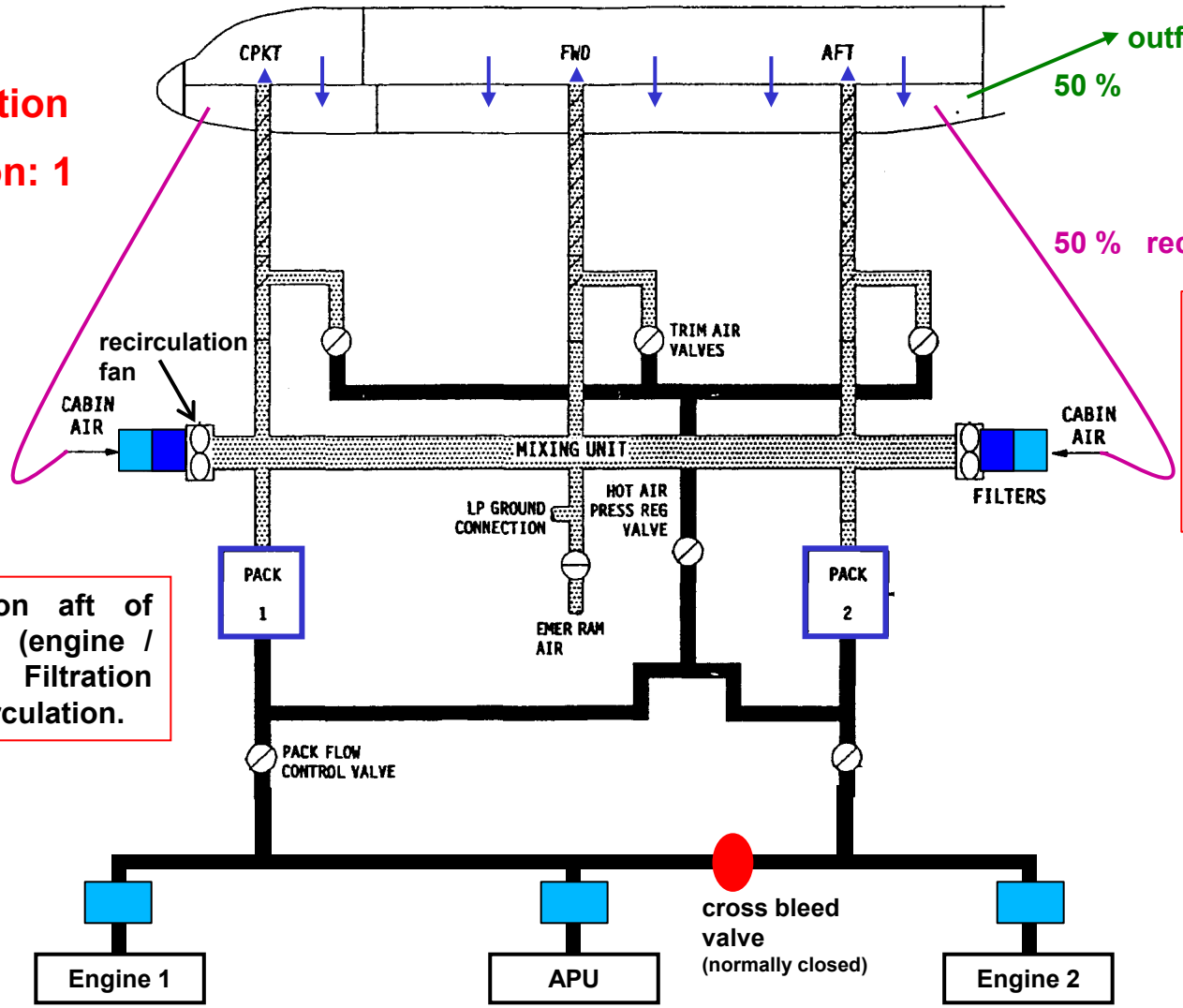


for $x_{fil} = 1$:

$$\frac{x_{cont,cab}}{x_{cont,in}} = 1 - x_{re}$$

Technical Solutions

Full Filtration Option: 1



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

$$\approx 0.3 \cdot 0.6 = 0.18$$

=> reduces incoming pollutant concentrations to ≈ 18%

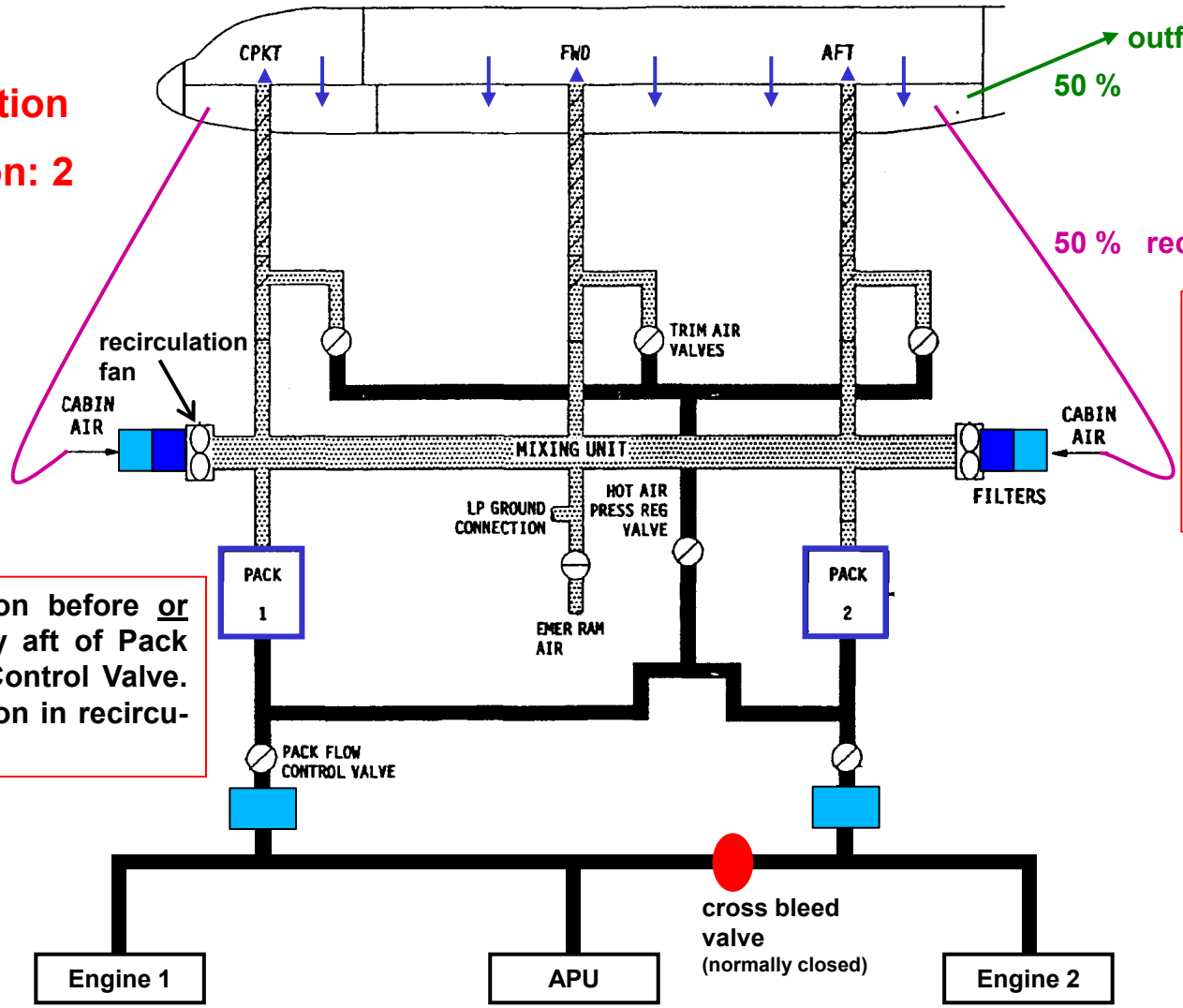
Filtration aft of source (engine / APU). Filtration in recirculation.

VOC Filter

Combined HEPA & VOC Filter
(HEPA-Carbon Filter)

Technical Solutions

Full Filtration Option: 2



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

$$\approx 0.3 \cdot 0.6 = 0.18$$

=> reduces incoming pollutant concentrations to ≈ 18%

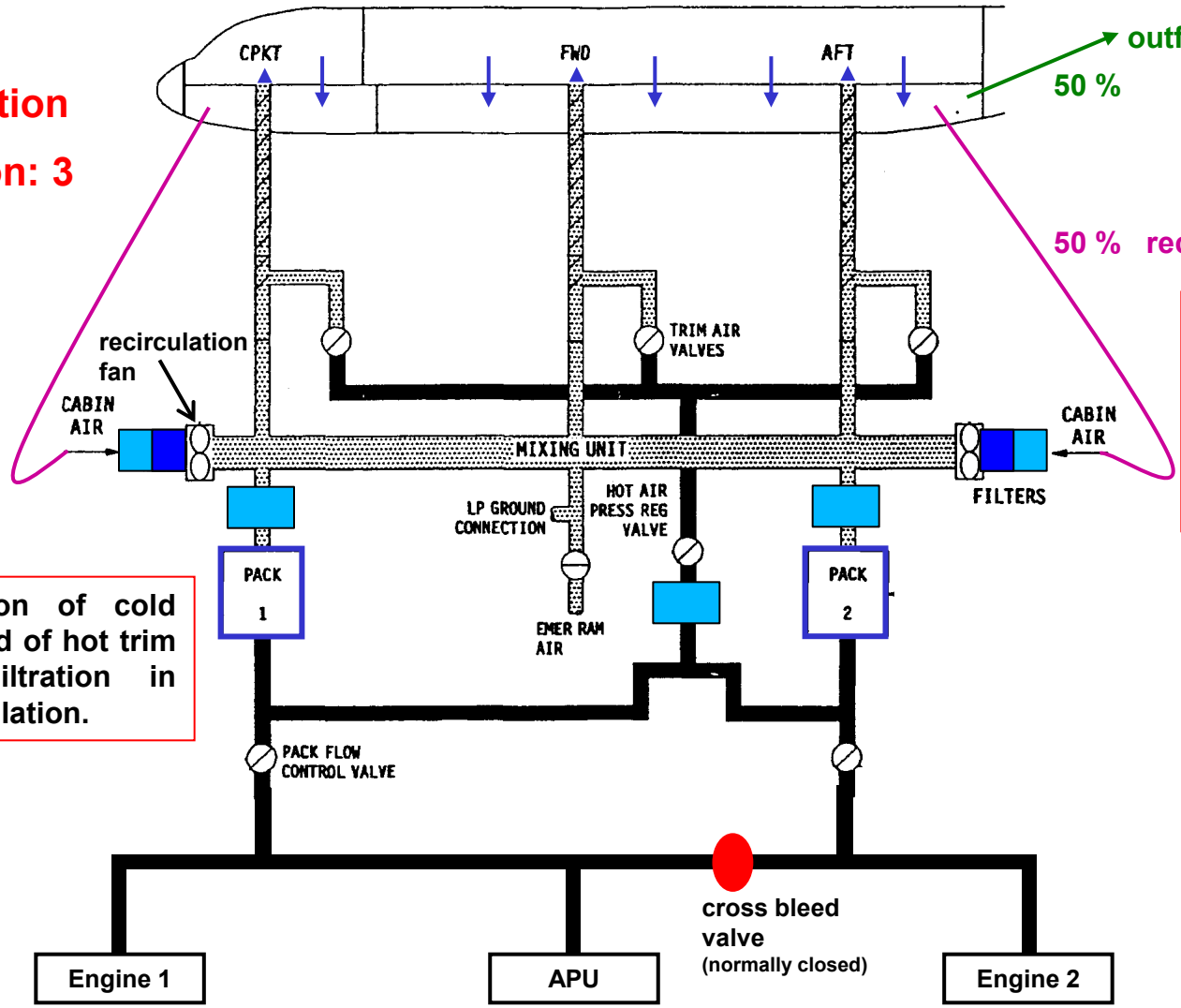
Filtration before or directly aft of Pack Flow Control Valve. Filtration in recirculation.

VOC Filter

Combined HEPA & VOC Filter
(HEPA-Carbon Filter)

Technical Solutions

Full Filtration Option: 3



$$f_{recirc} = \frac{1 - x_{re}}{1 - (1 - x_{fil}) x_{re}}$$

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

$$\approx 0.3 \cdot 0.6 = 0.18$$

=> reduces incoming pollutant concentrations to ≈ 18%

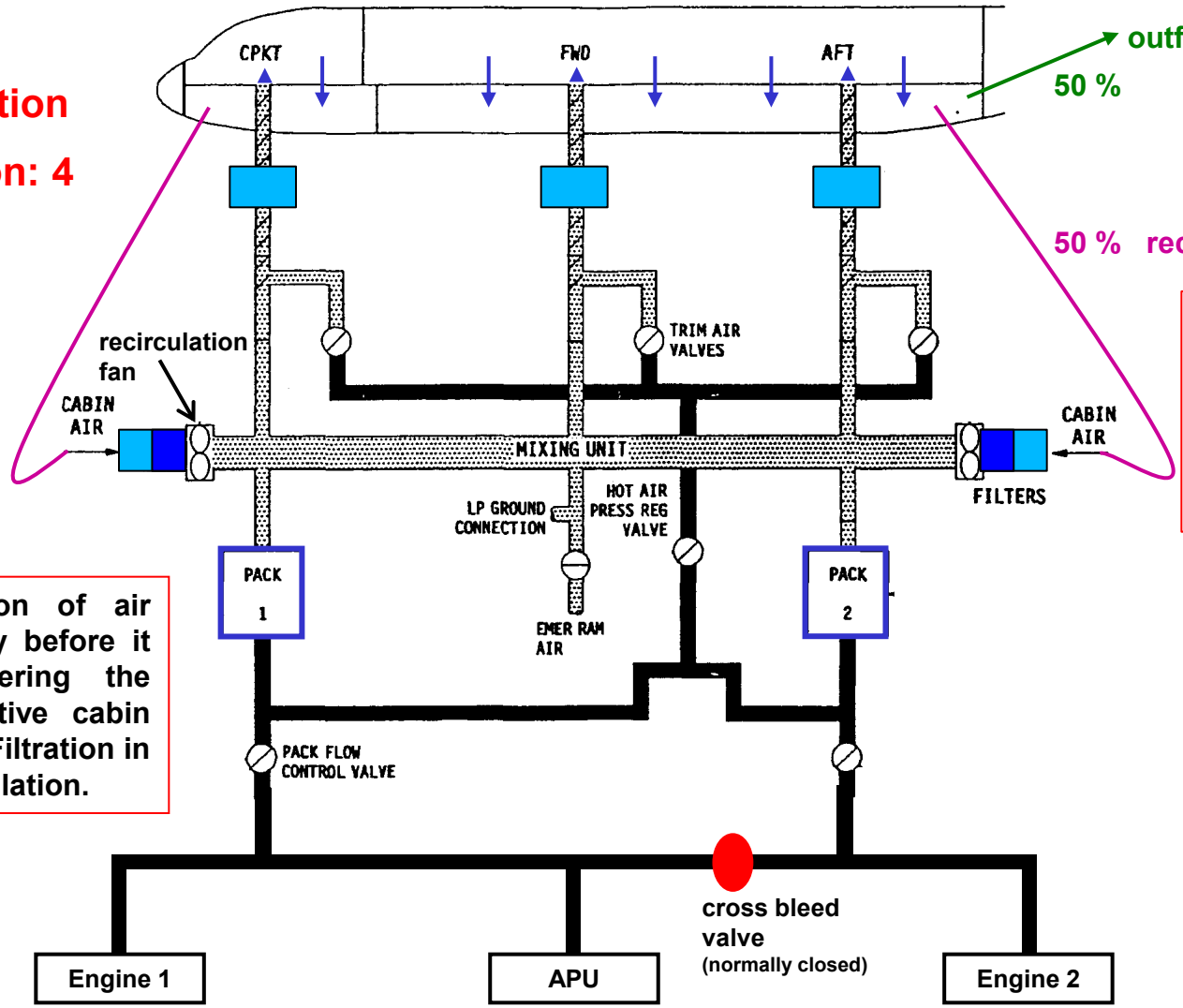
Filtration of cold air and of hot trim air. Filtration in recirculation.

VOC Filter

Combined HEPA & VOC Filter
(HEPA-Carbon Filter)

Technical Solutions

Full Filtration Option: 4



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

$$\approx 0.3 \cdot 0.6 = 0.18$$

=> reduces incoming pollutant concentrations to ≈ 18%

Filtration of air directly before it is intering the respective cabin zone. Filtration in recirculation.

VOC Filter

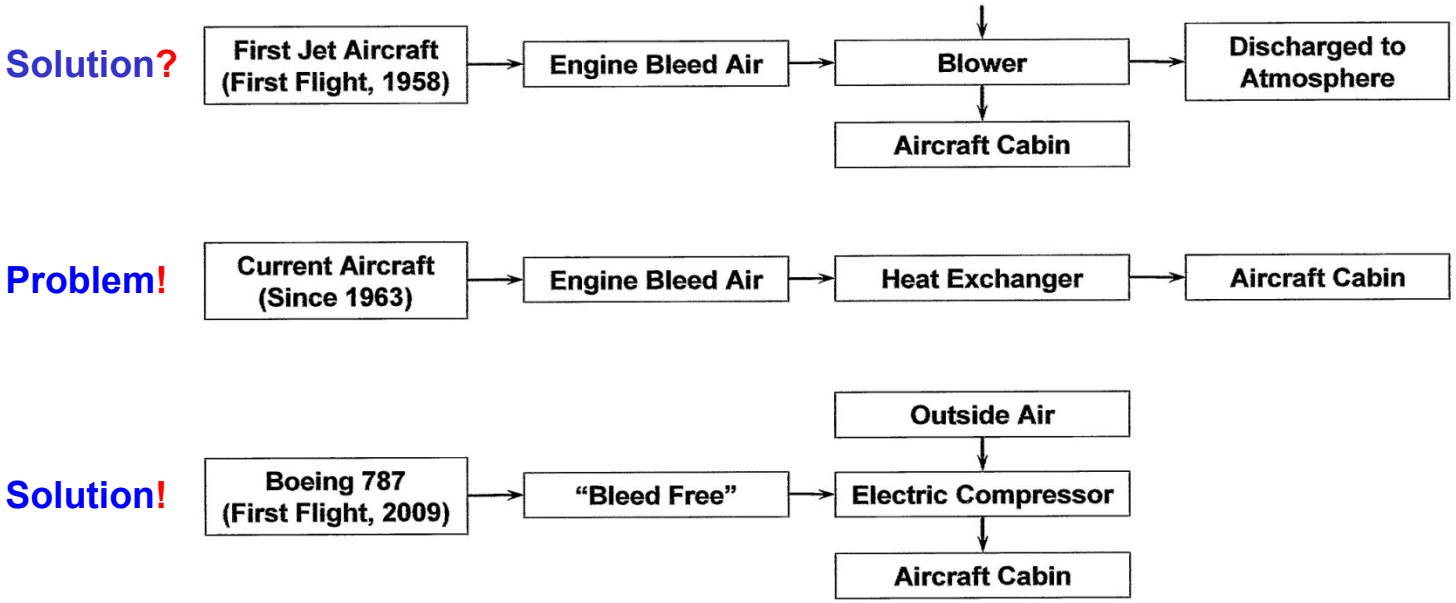
Combined HEPA & VOC Filter
(HEPA-Carbon Filter)

Technical Solutions

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".



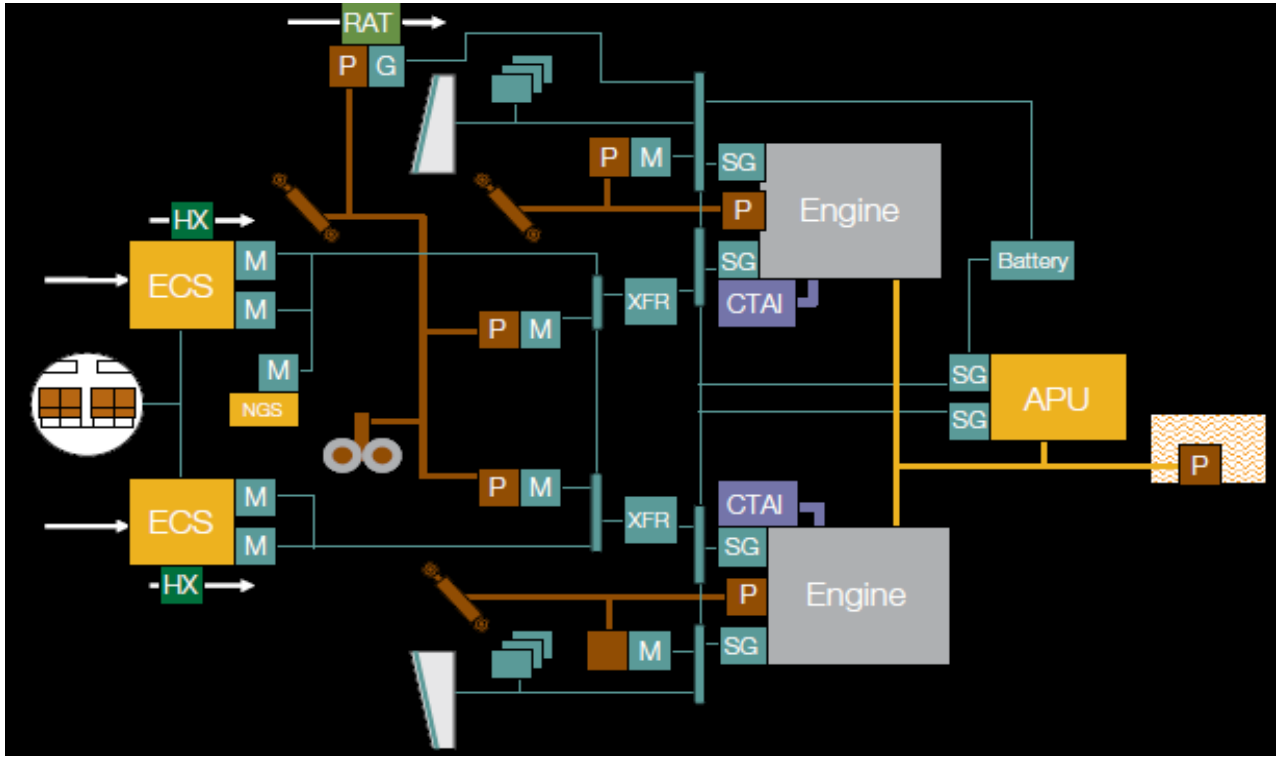
(Michaelis 2010)

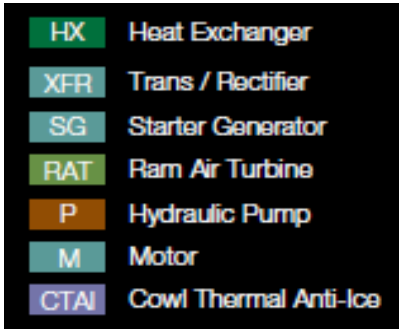
Technical Solutions

Electrical (Bleed Free) Cabin Air Supply

Solution B787!

Boeing 2007



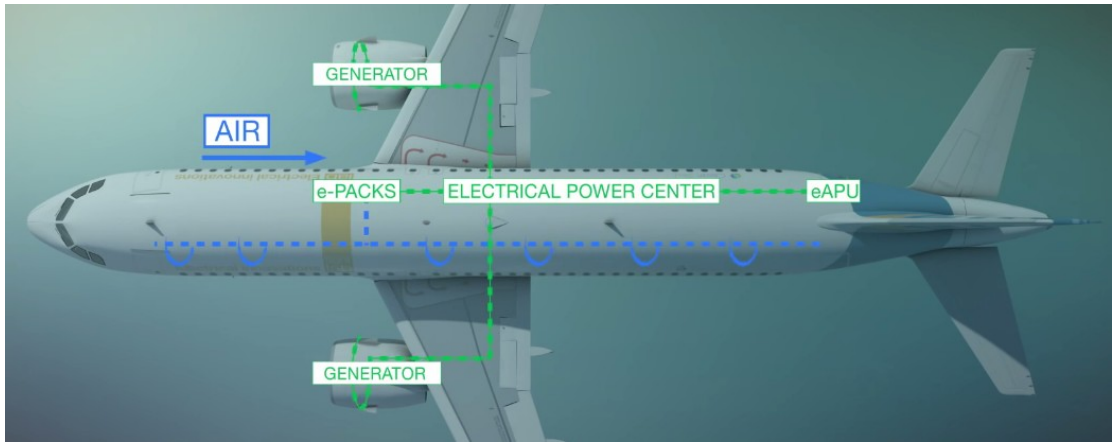


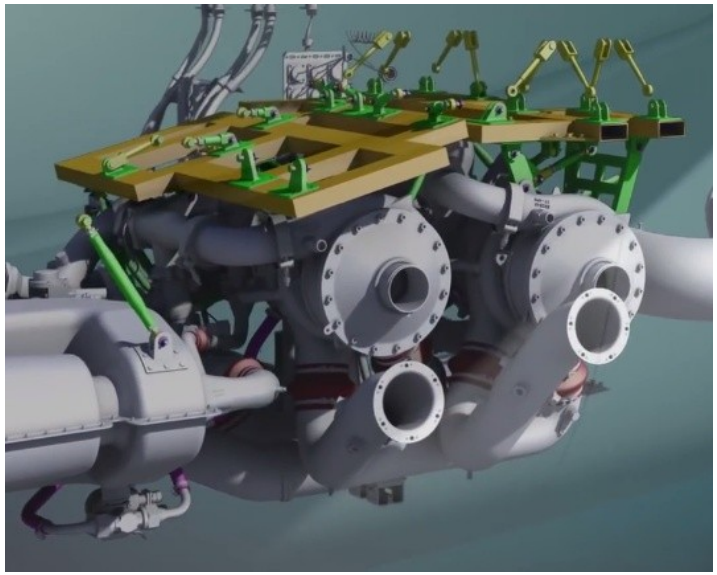
The "Pack" of the B787's Environmental Control System (ECS) is powered by electric motors (M) to compress ambient air up to cabin pressure and to push the air through the heat exchangers (HX) for cooling. The power for the electric motors is produced by generators (SG) connected to the aircraft's engine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

Technical Solutions

More Electric A320?

Electrical innovations
flightlab



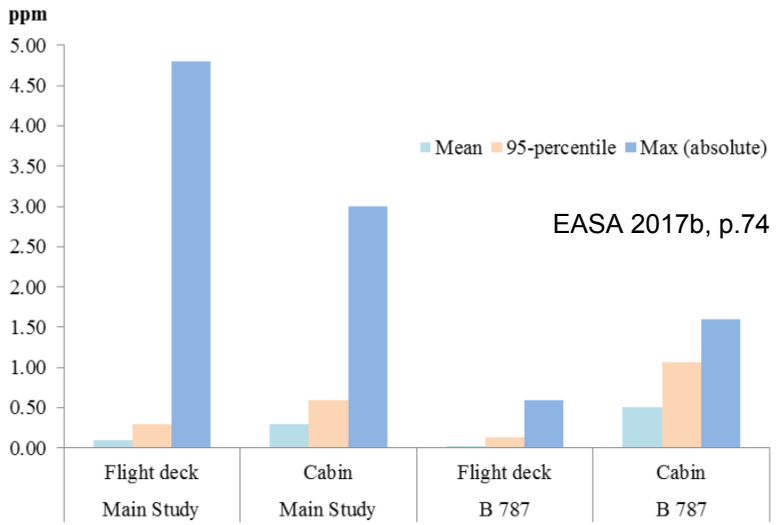


Hints (for Today!)

Hints

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

Normal CO Situation



EASA 2017b, p.74

- 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 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.**

Failure Case: Fume Event

Get CO Detector and Breathing Mask

Cabin crew protection !

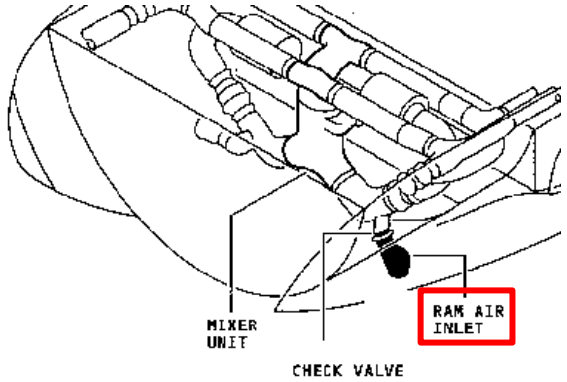
Hints

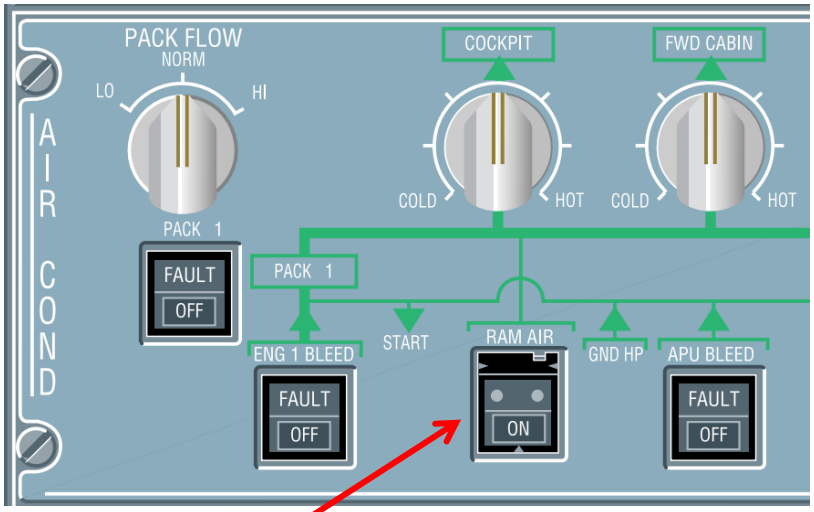
Direct Venting of the Cabin in 10000 ft

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.

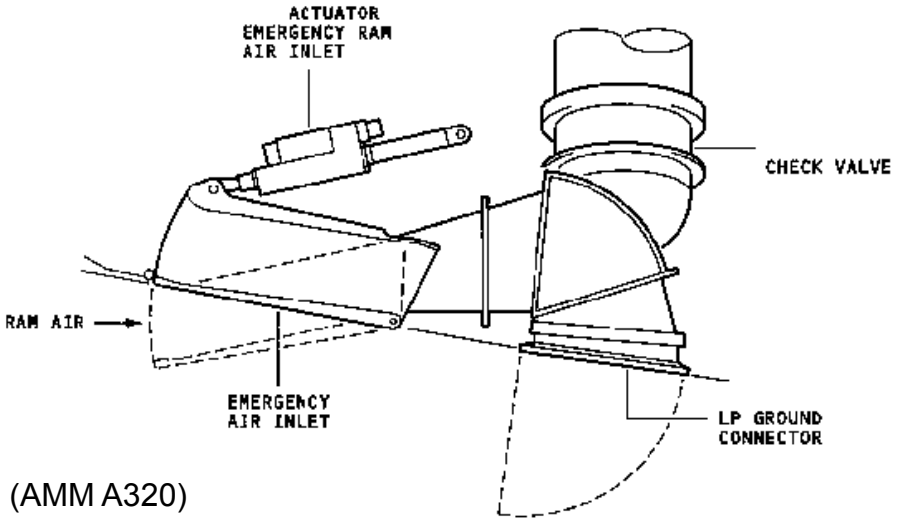
Component location





guarded pushbutton

Emergency ram air inlet



(AMM A320)

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!

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A **List of References** is contained in my presentation from 19.09.2017