Aero

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

AIRCRAFT DESIGN AND SYSTEMS GROUP (AERO)

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

GCAQE
Global Cabin Air Quality Executive

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QCAQE – Global Cabin Air Quality Executive
SEVENTH ANNUAL FORUM and INFORMATION EXCHANGE
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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.

SCHOLZ, Dieter: Aircraft Systems. In: DAVIES, Mark: The Standard Handbook for Aeronautical and Astronautical Engineers. New York : McGraw-Hill, 2003

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.

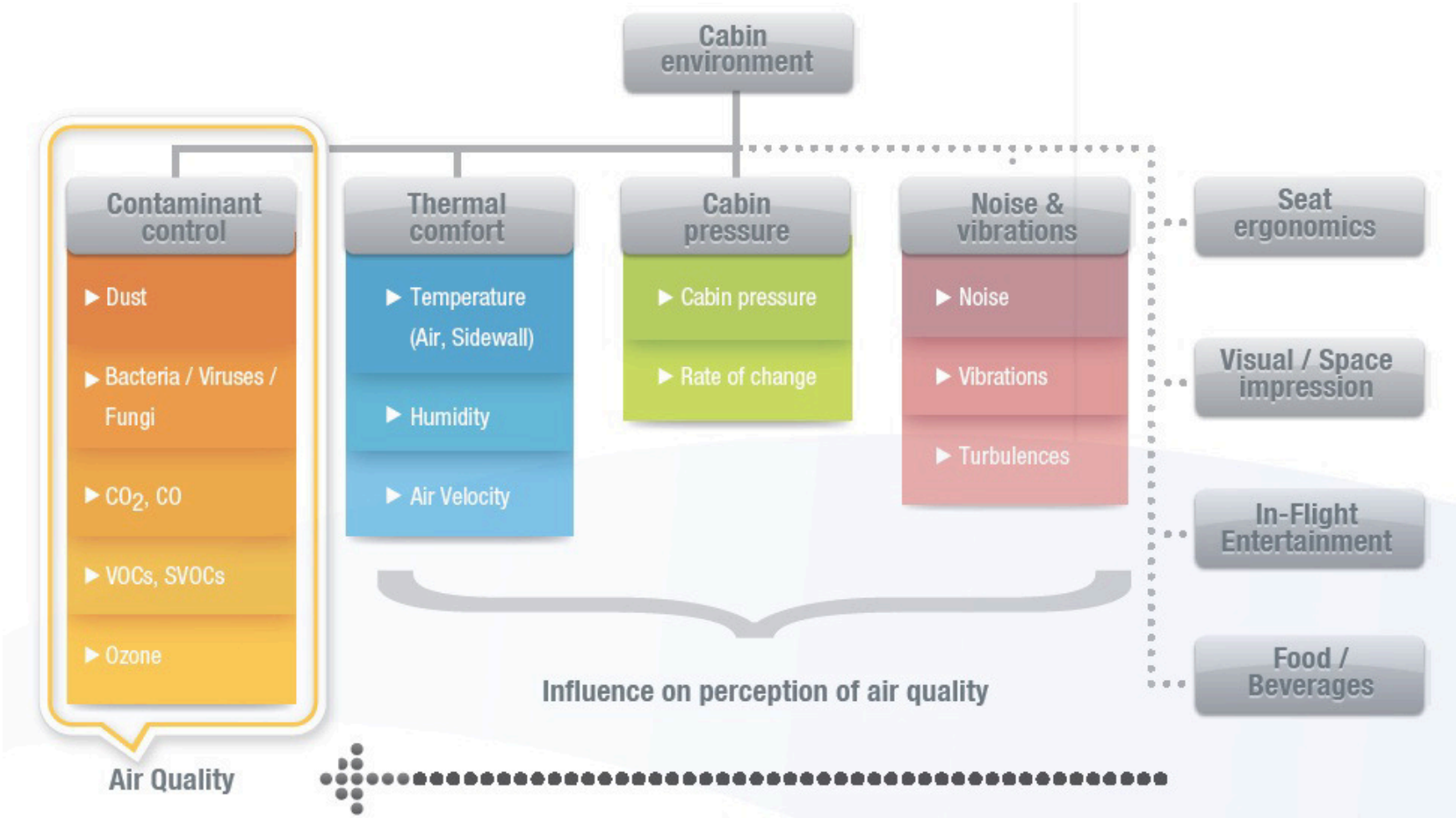
Adapted from: http://en.wikipedia.org/wiki/Contamination

Definition: **Quality**

Degree to which a set of inherent characteristics fulfills requirements.

ISO 9000

Introduction



http://bloga350.blogspot.com.ar/2012/11/a350-xwb-cabin-air-quality-will-make.html

Introduction

Requirement: **SAE 1796: Engine Bleed Air Systems for Aircraft** (1987, A in 2007, B in 2012)

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

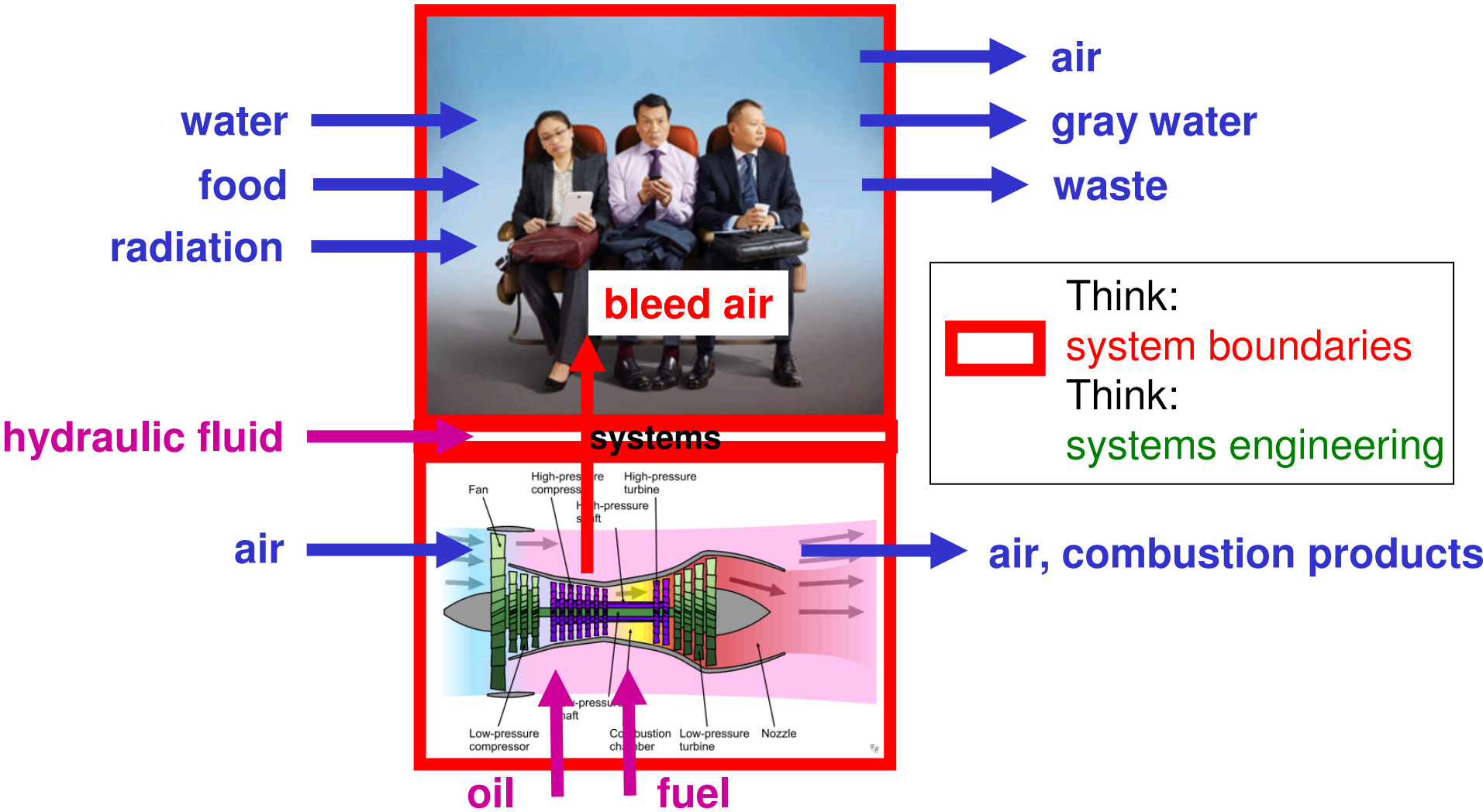
Under normal operating conditions:
The engine bleed air shall be **free of engine-generated objectionable** odors, irritants, and/or **toxic** of incapacitating foreign **materials**.

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



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

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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://aircrewhealth.com/Topics/hazards/cabinair.htm

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.

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- Systematic Solution
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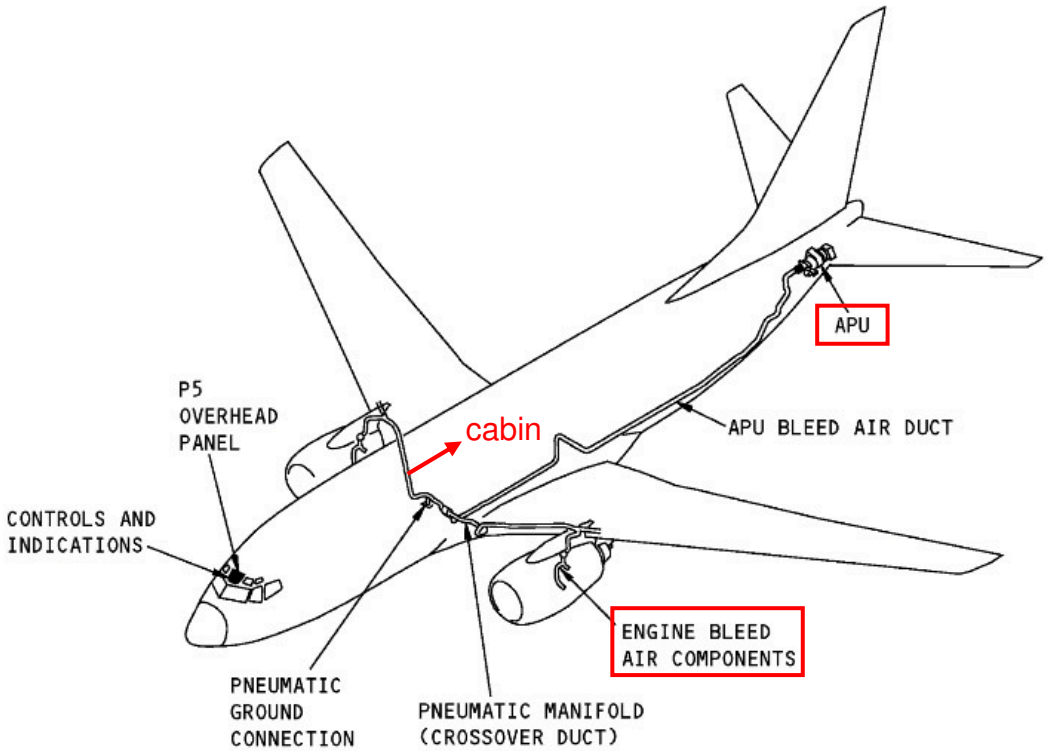
Aircraft Systems Investigated - Major Component Location

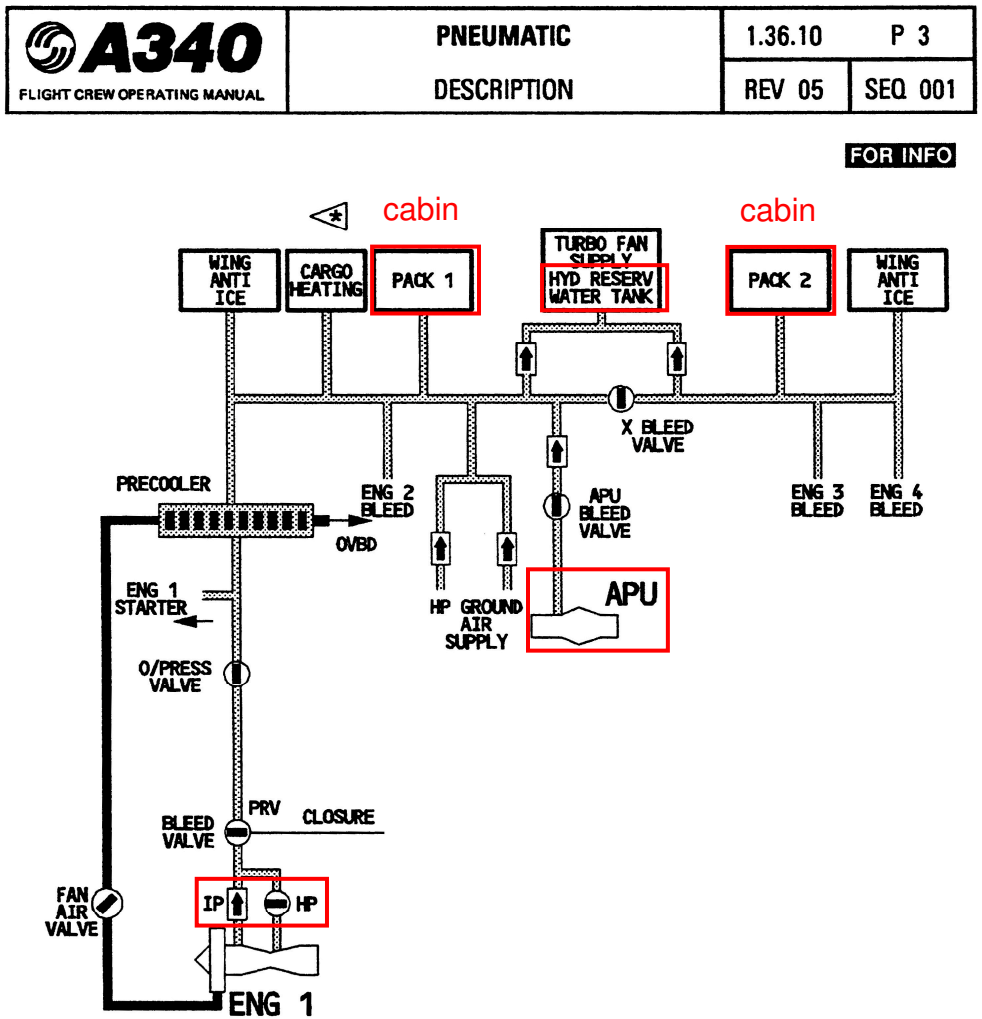
BOEING

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

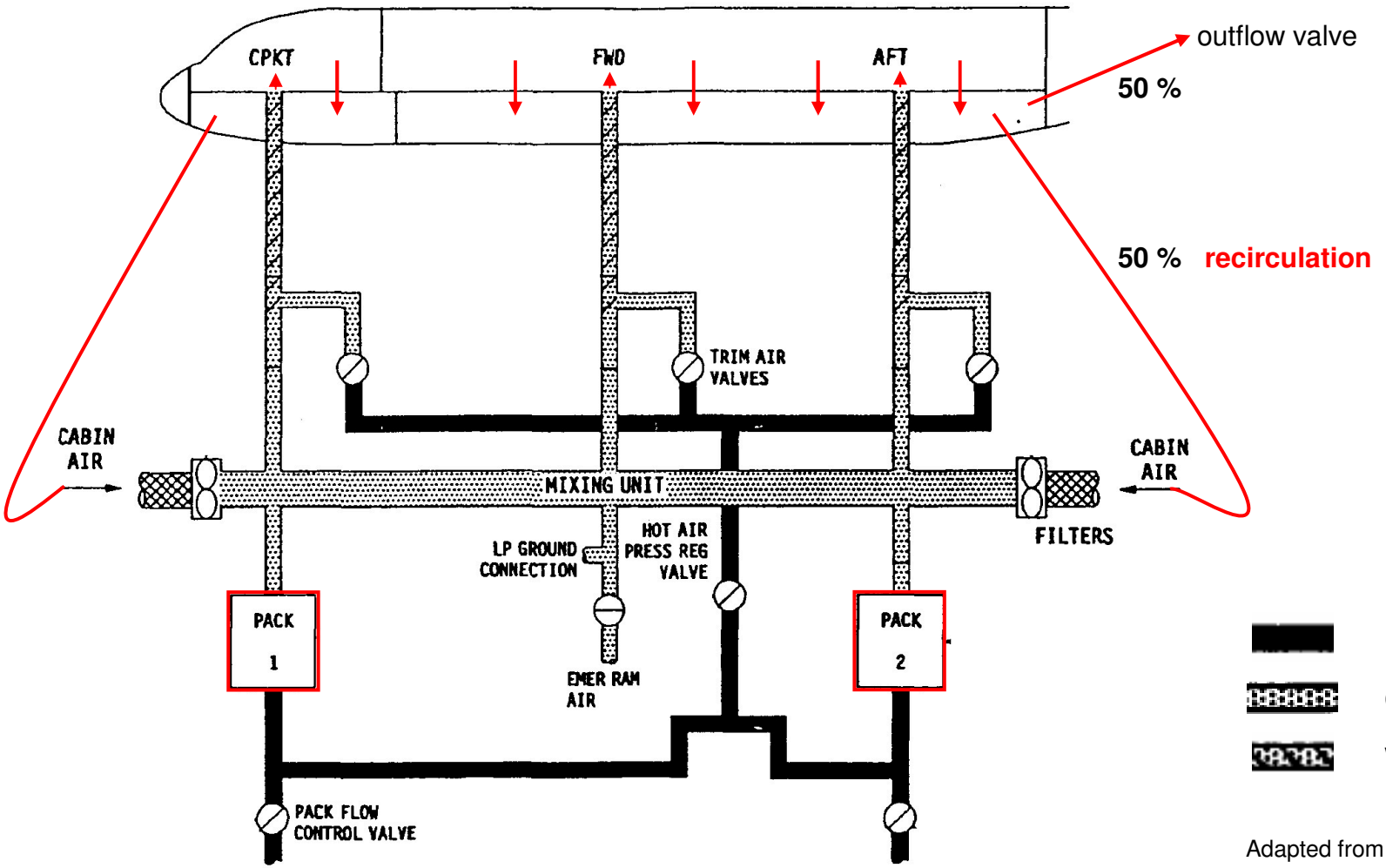


PNEUMATIC - COMPONENT LOCATIONS

Aircraft Systems Investigated - Bleed Air to Cabin Overview (1)

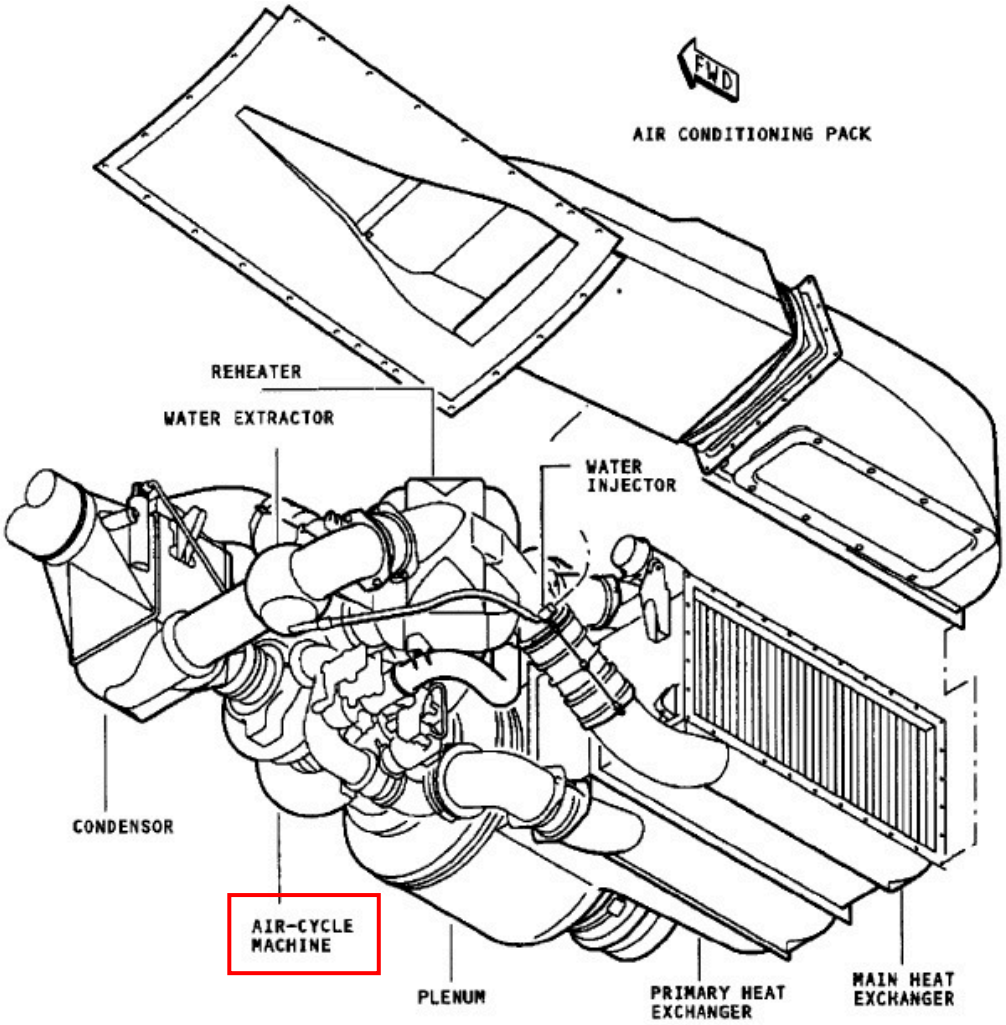


Aircraft Systems Investigated - Bleed Air to Cabin Overview (2)

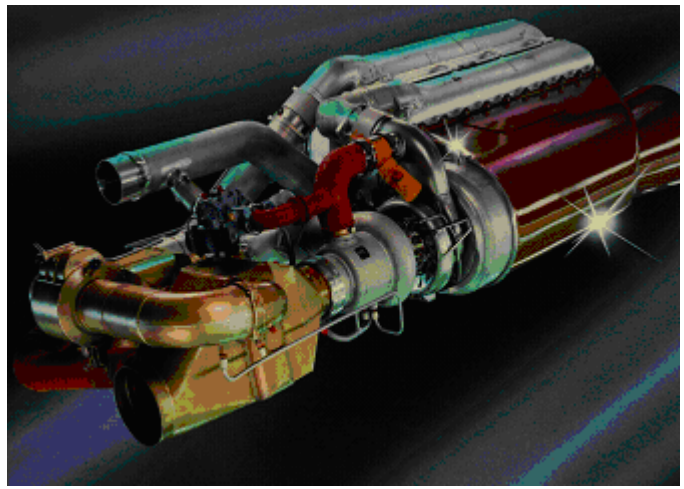


Adapted from FCOM A320

Aircraft Systems Investigated - Air Conditioning Pack (1)

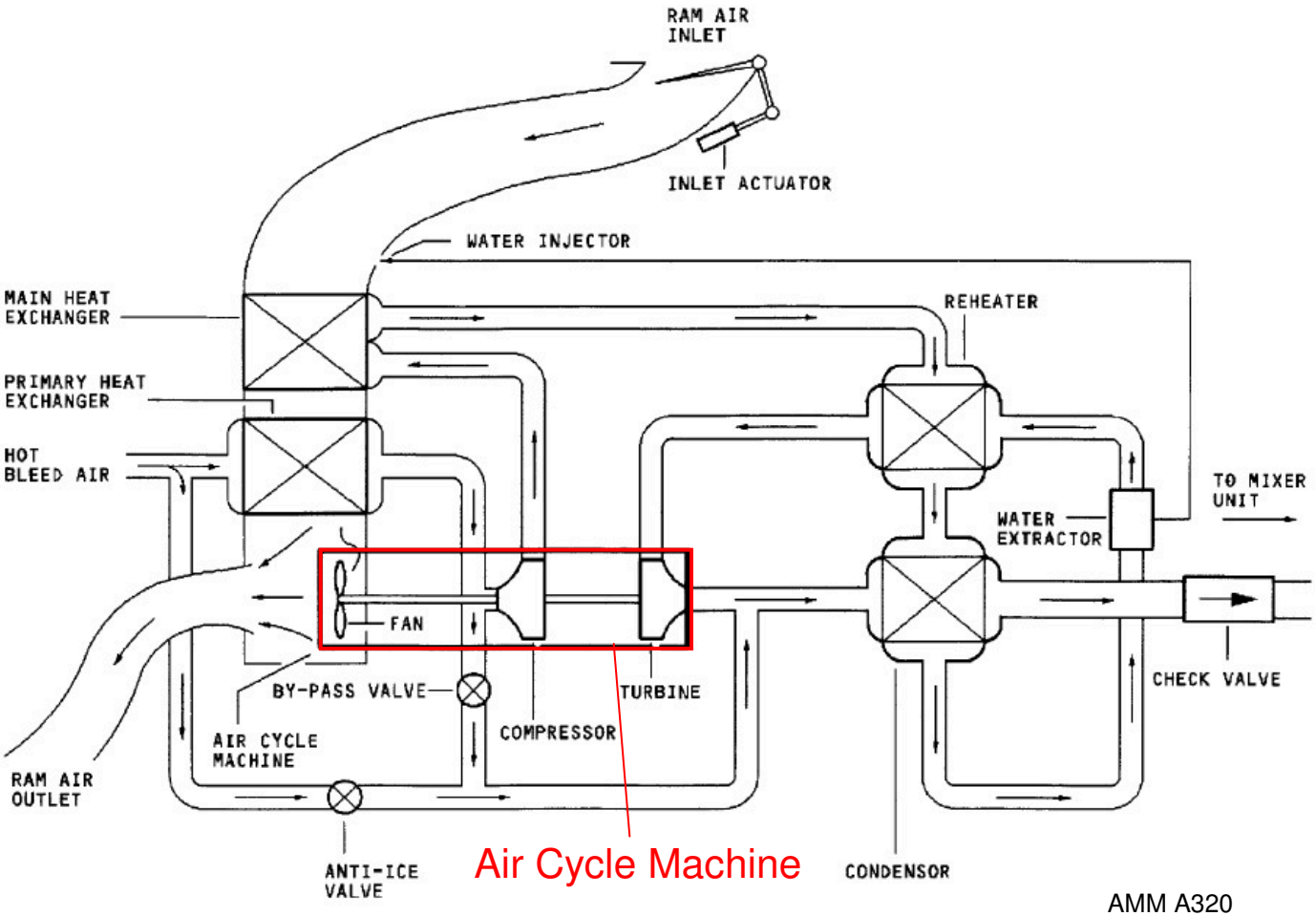


AMM A320



Liebherr Aerospace

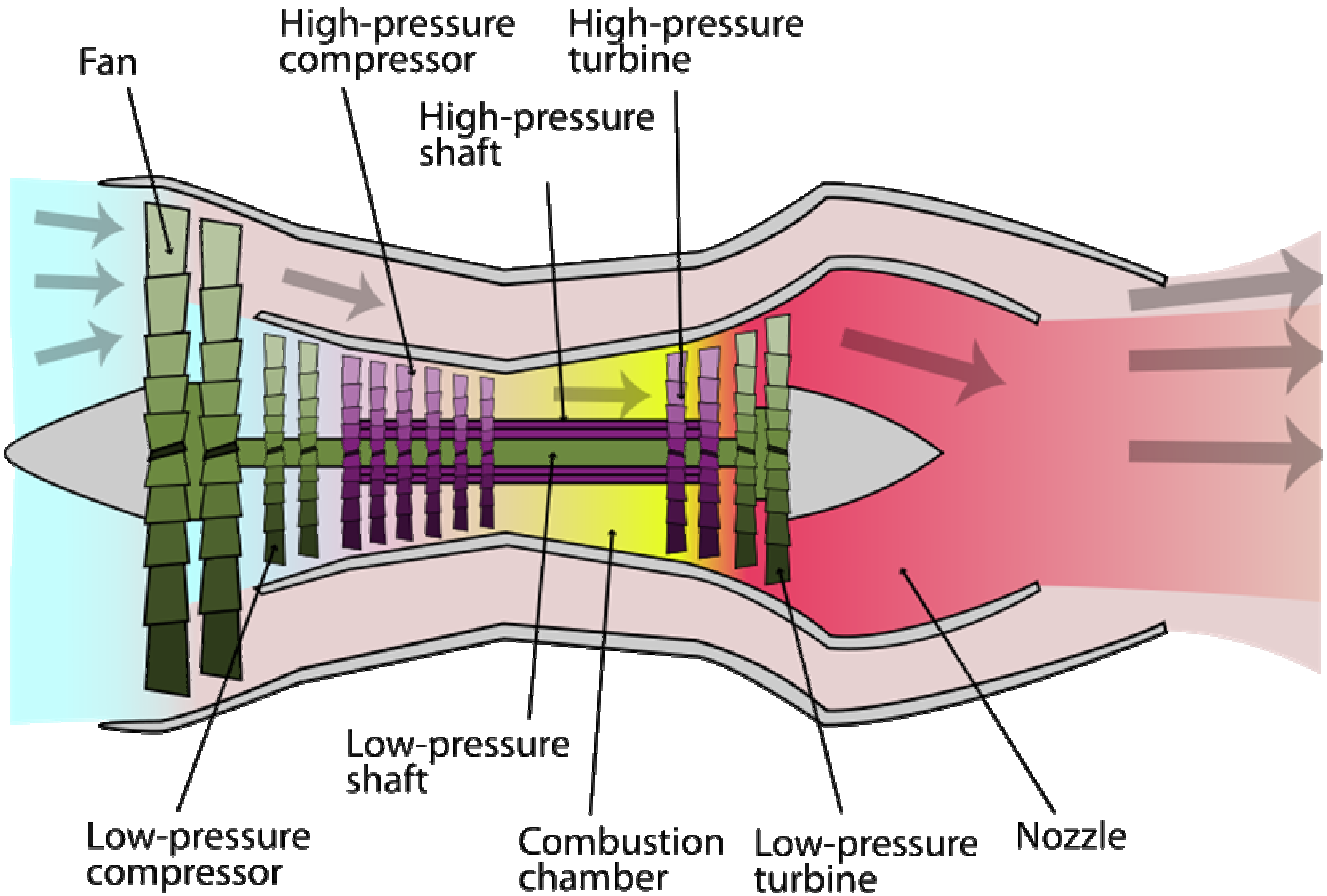
Aircraft Systems Investigated - Air Conditioning Pack (2)



AMM A320

- 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



K. Aainsqatsi, Wikipedia.org

Aircraft Systems Investigated - Engine Overview

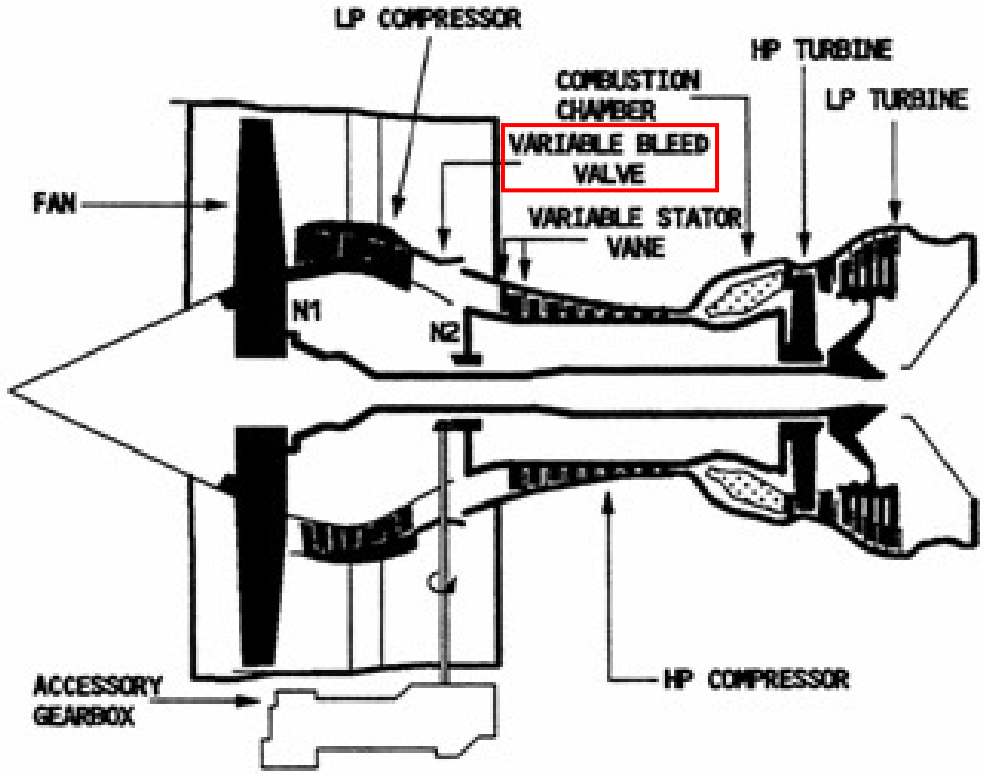
A340 FLIGHT CREW OPERATING MANUAL	POWER PLANT	1.70.10	P 1
	ENGINE	REV 05	SEQ 005

GENERAL

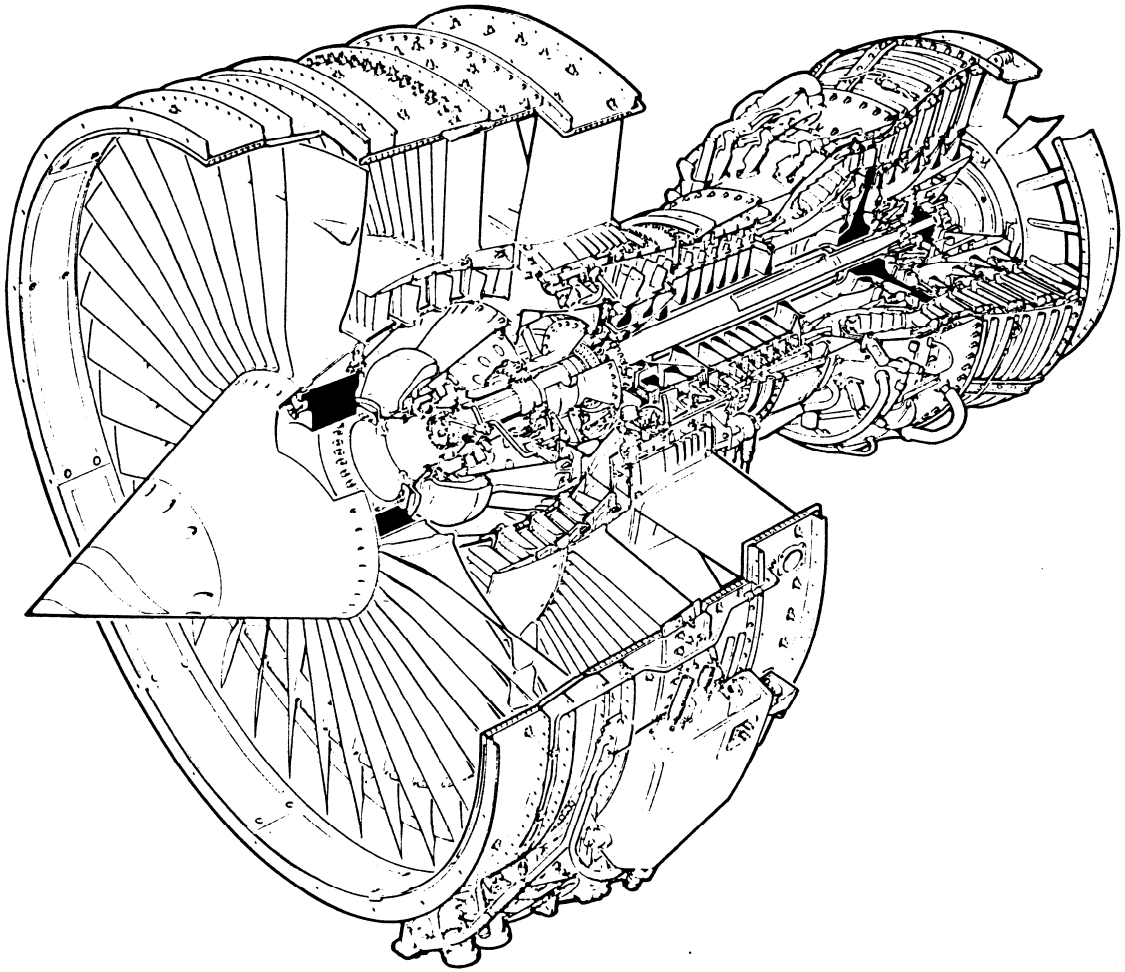
The CFM 56–5–C2 engine is a high bypass ratio turbofan, rated at a 31200 pounds take-off thrust at sea level and flat rated to ISA + 15°C. The engine has a fan air to primary air by-pass ratio of 6.6 to 1.

DESCRIPTION

- **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.

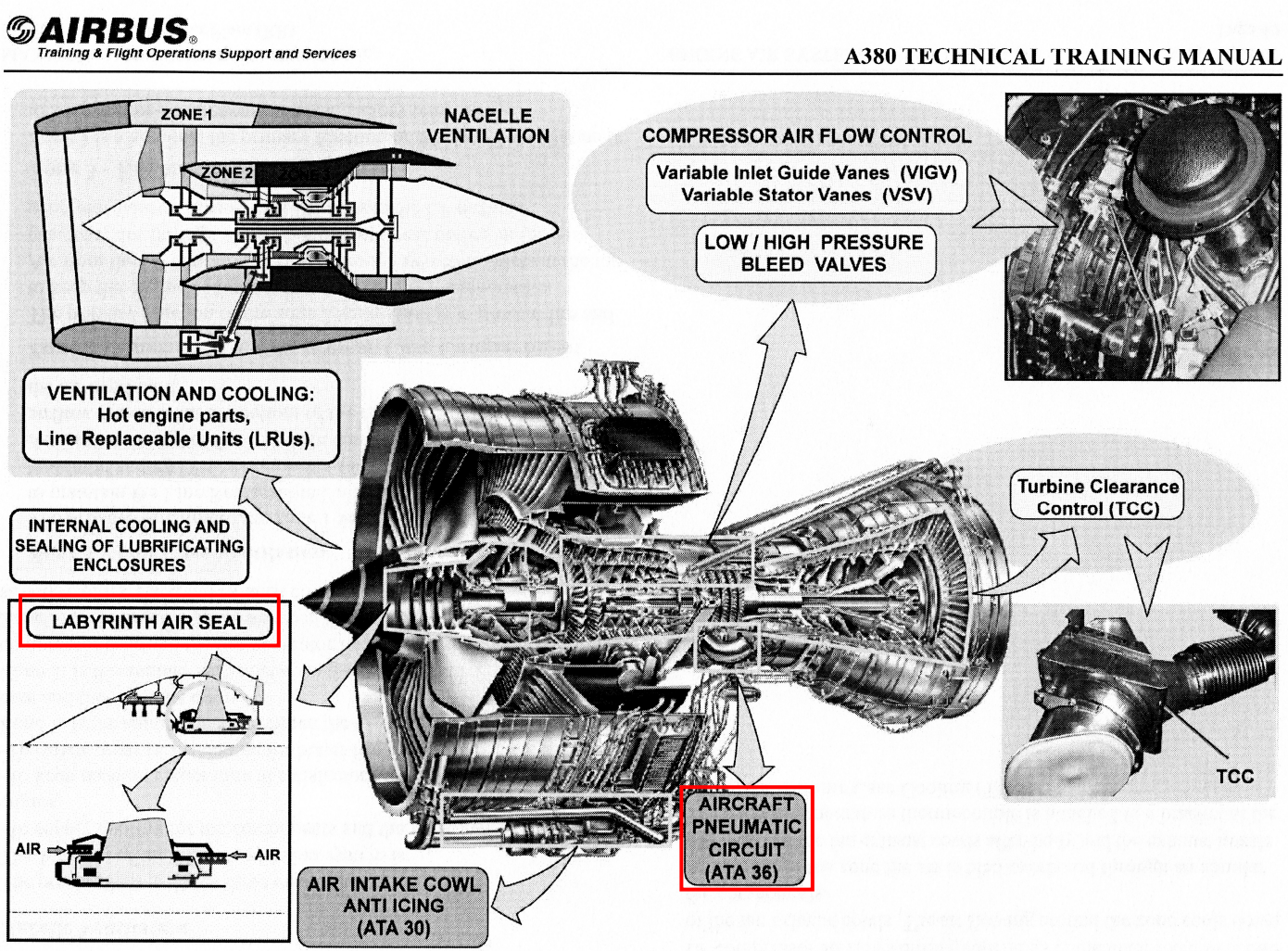


Aircraft Systems Investigated - Engine Overview



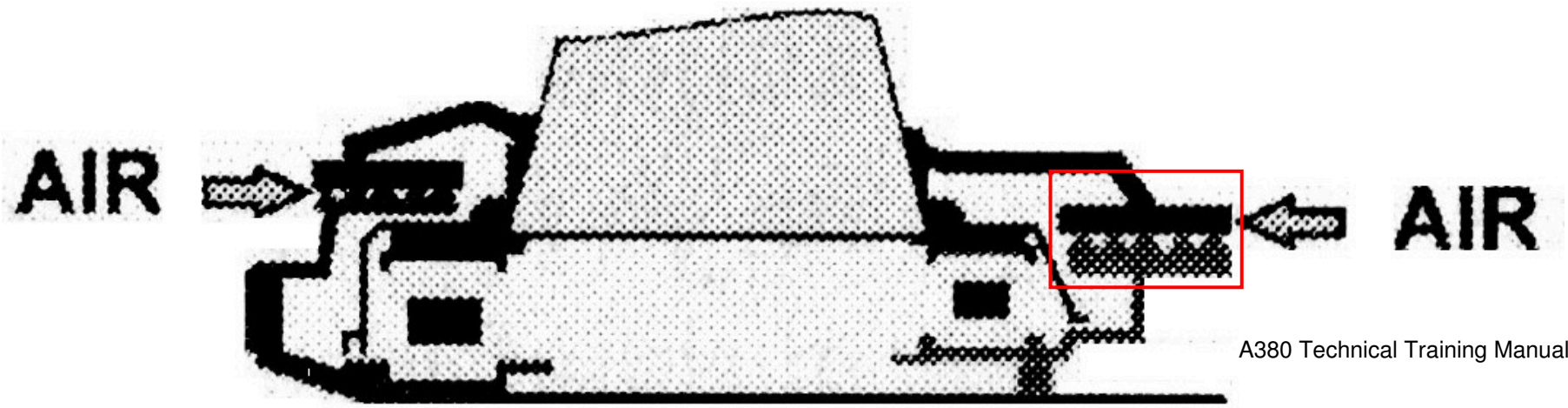
A320 Training Manual: CFM 56-5

Aircraft Systems Investigated - Engine Overview



RR Trent 900

Aircraft Systems Investigated - Labyrinth Seal



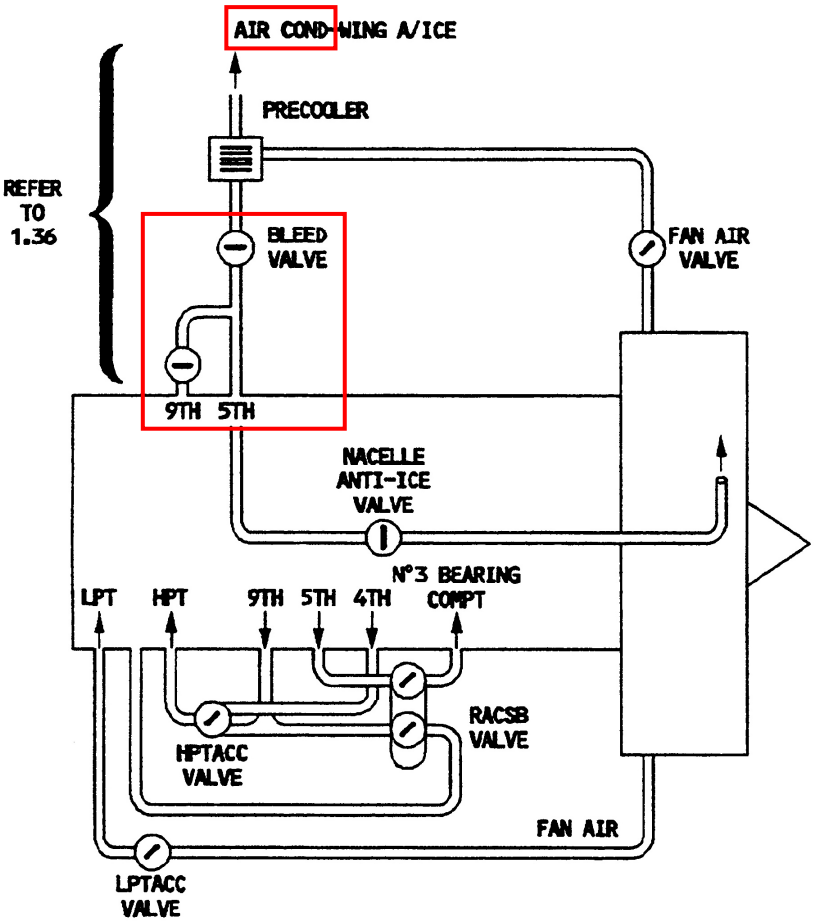
A380 Technical Training Manual

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

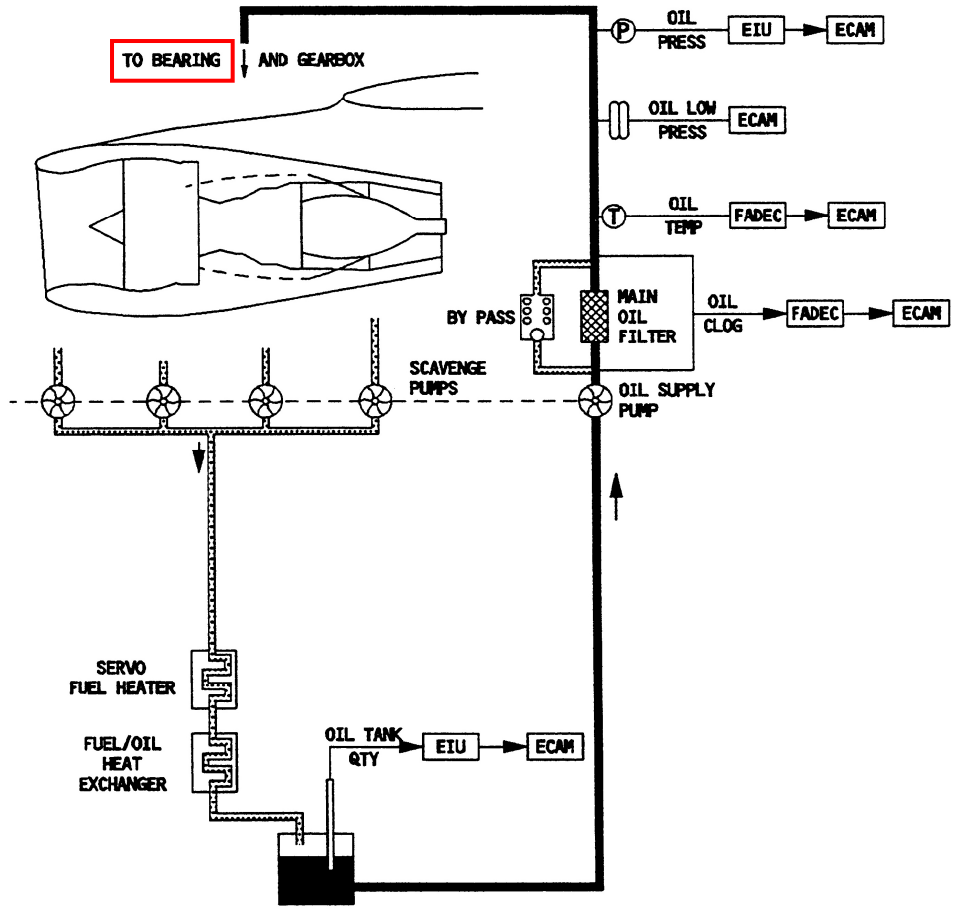
The **CAA has** already **taken** remedial **action to** help operators of particular aircraft reduce the incidence of fume events e.g. engine oil servicing procedures and **engine sealing** modifications.

https://www.gov.uk/government/publications/cabin-air-quality-faq

Aircraft Systems Investigated - Engine Air and Oil System



FCOM A340: Engine Air System

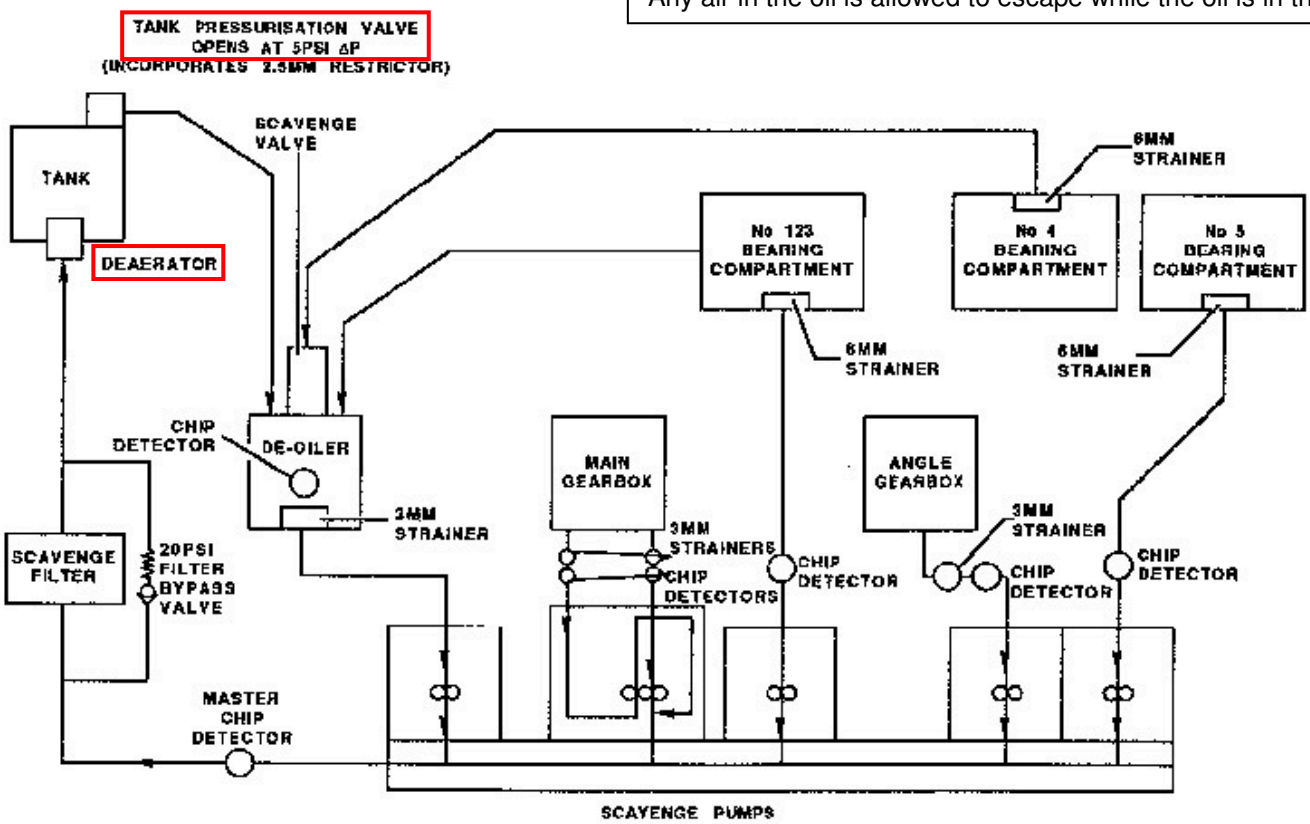


FCOM A340: Engine Oil System

Aircraft Systems Investigated - Engine Air and Oil System

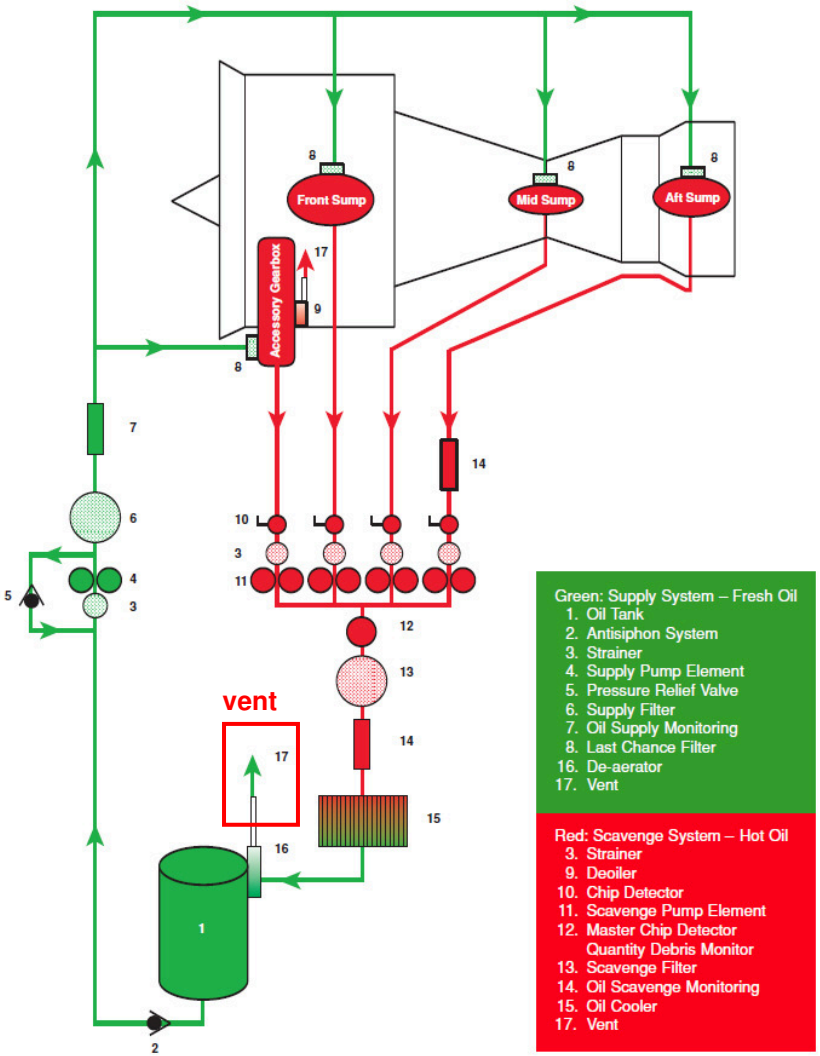
Deaerator:
A chamber in the lubrication system of a gas turbine engine in which the return oil from the engine collects before it is returned to the reservoir. Any air in the oil is allowed to escape while the oil is in this chamber.

Oil Scavenge and Vent Systems



AMM A320

Aircraft Systems Investigated - Engine Air and Oil System

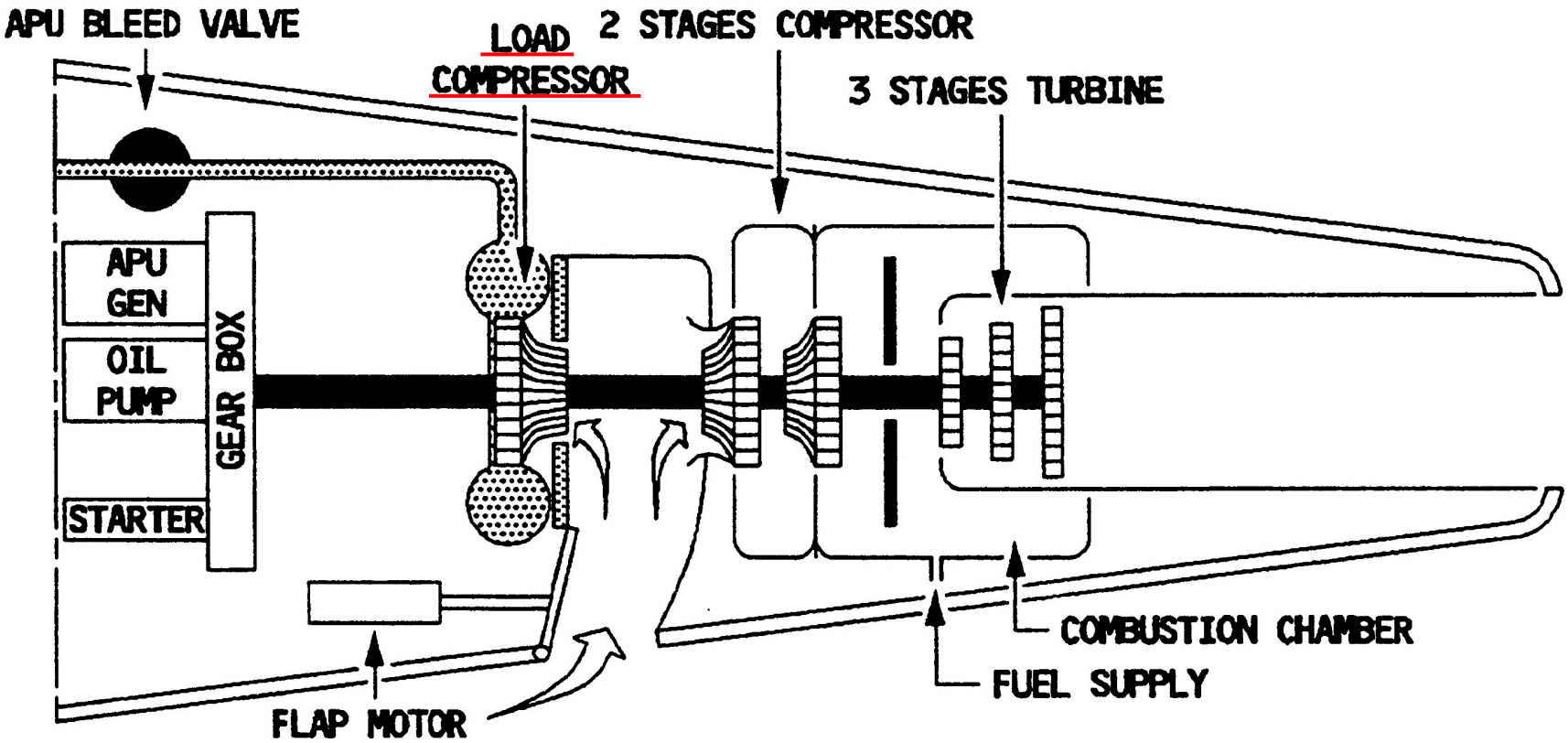


Quotes from: Exxon Mobile: "Jet Engine Oil System" with remarks:

- "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.)

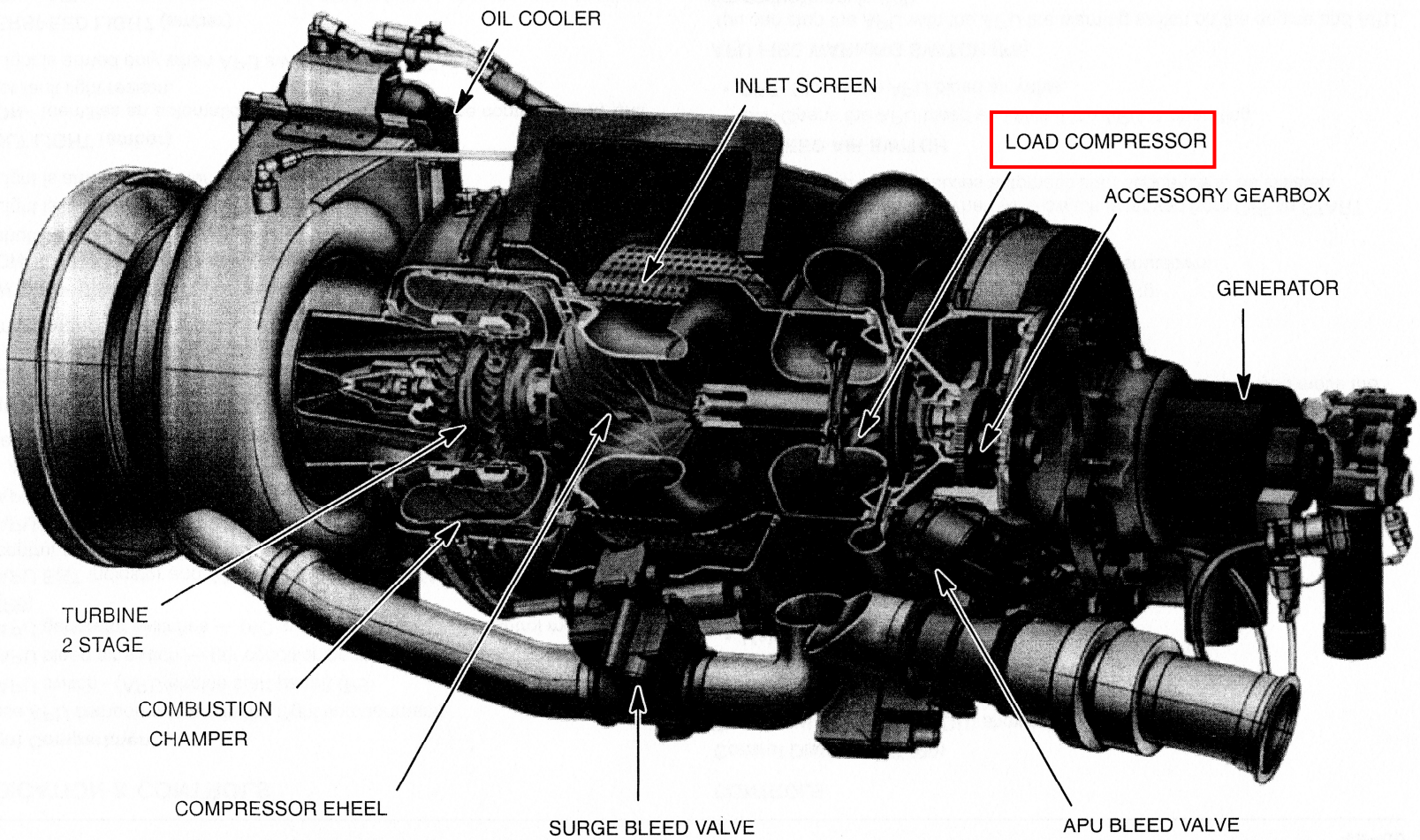
https://www.exxonmobil.com/lubes/exxonmobil/emal/files/TTopic13_JetEng1.pdf

Aircraft Systems Investigated - APU - Overview



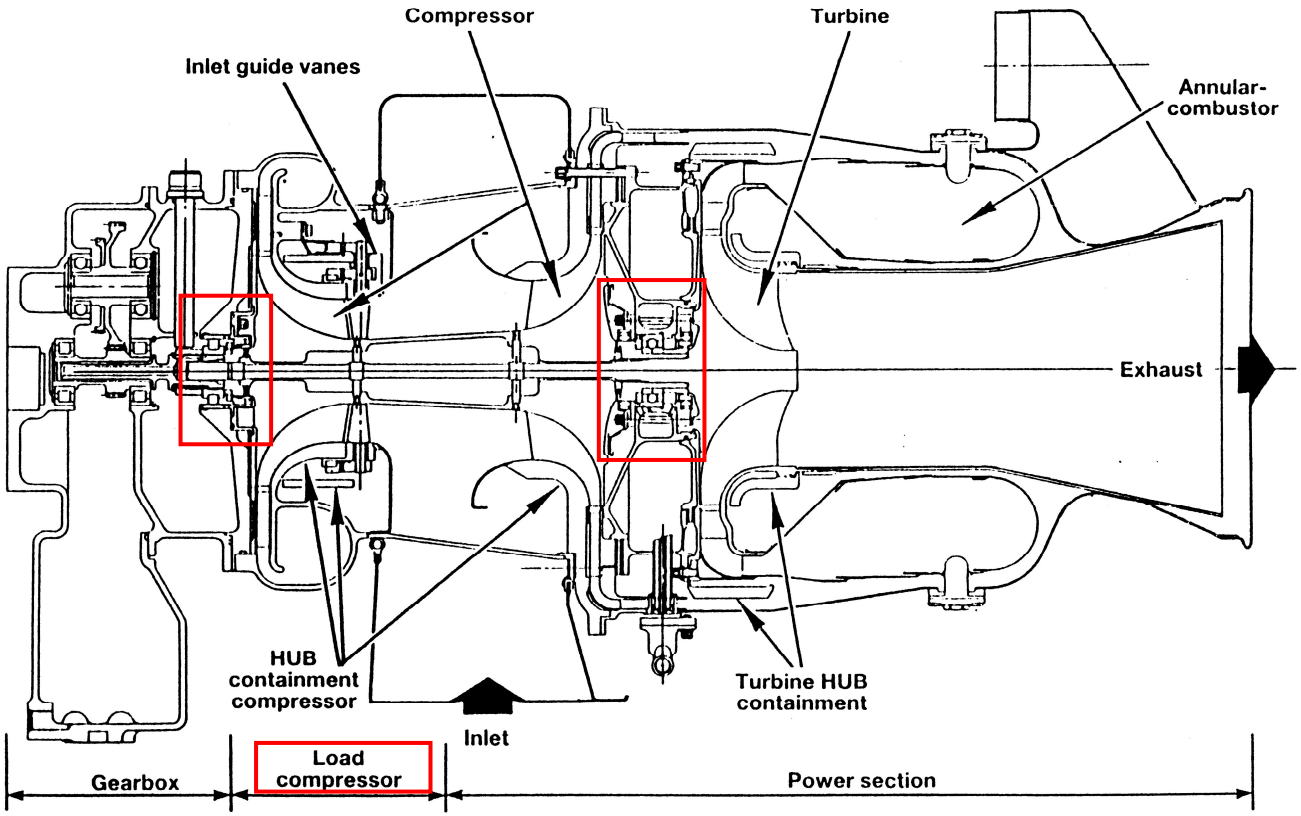
FCOM A340: APU Description

Aircraft Systems Investigated - APU - Overview



GENFAM LHT B737 APU AlliedSignal 131-9B

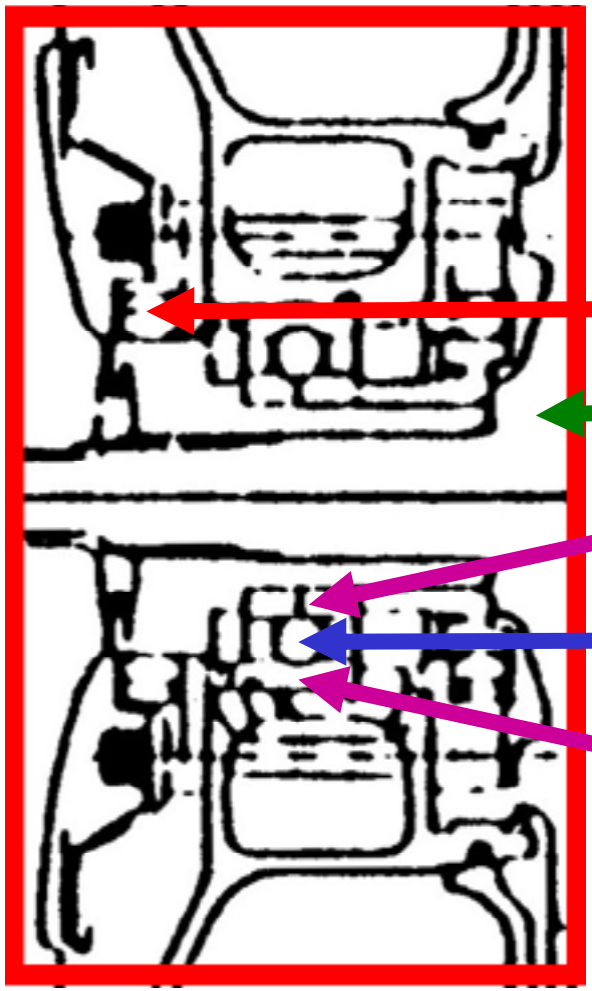
Aircraft Systems Investigated - APU with Bearings and Load Compressor



- 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.

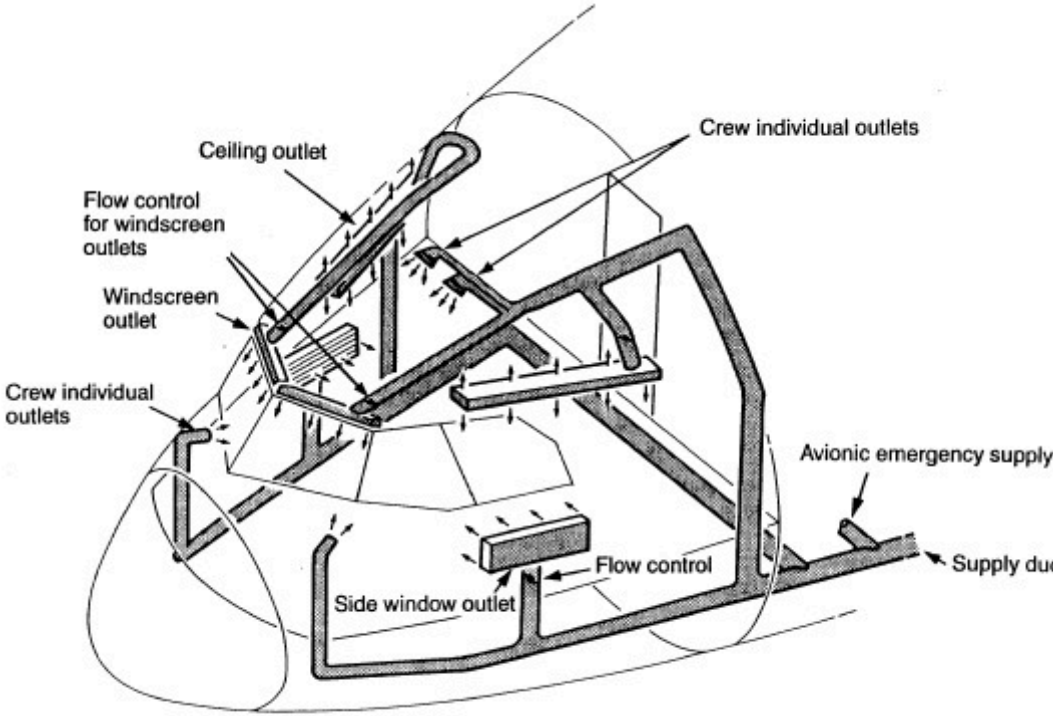
GENFAM A320 APU GTCP36-300

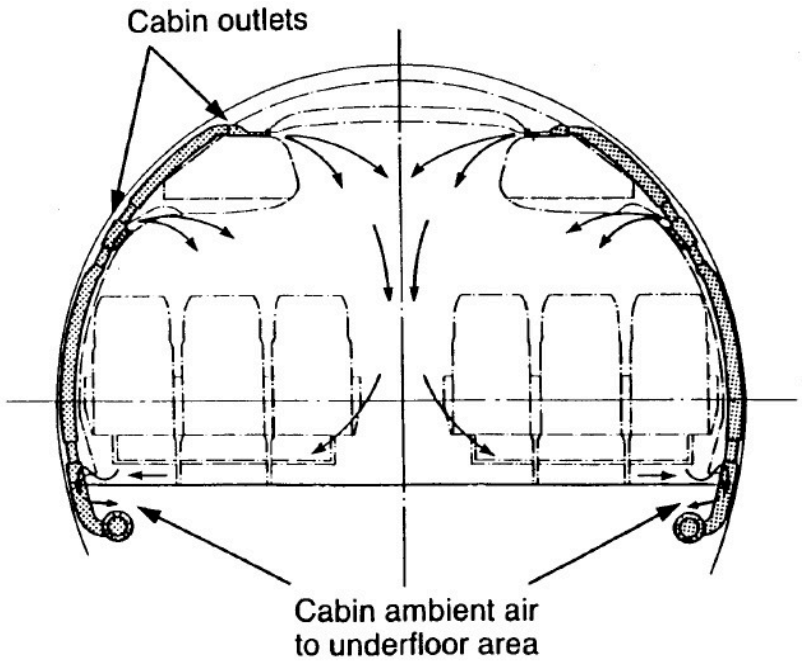
Aircraft Systems Investigated - APU with Bearings - Enlargements



GENFAM A320 APU GTCP36-300

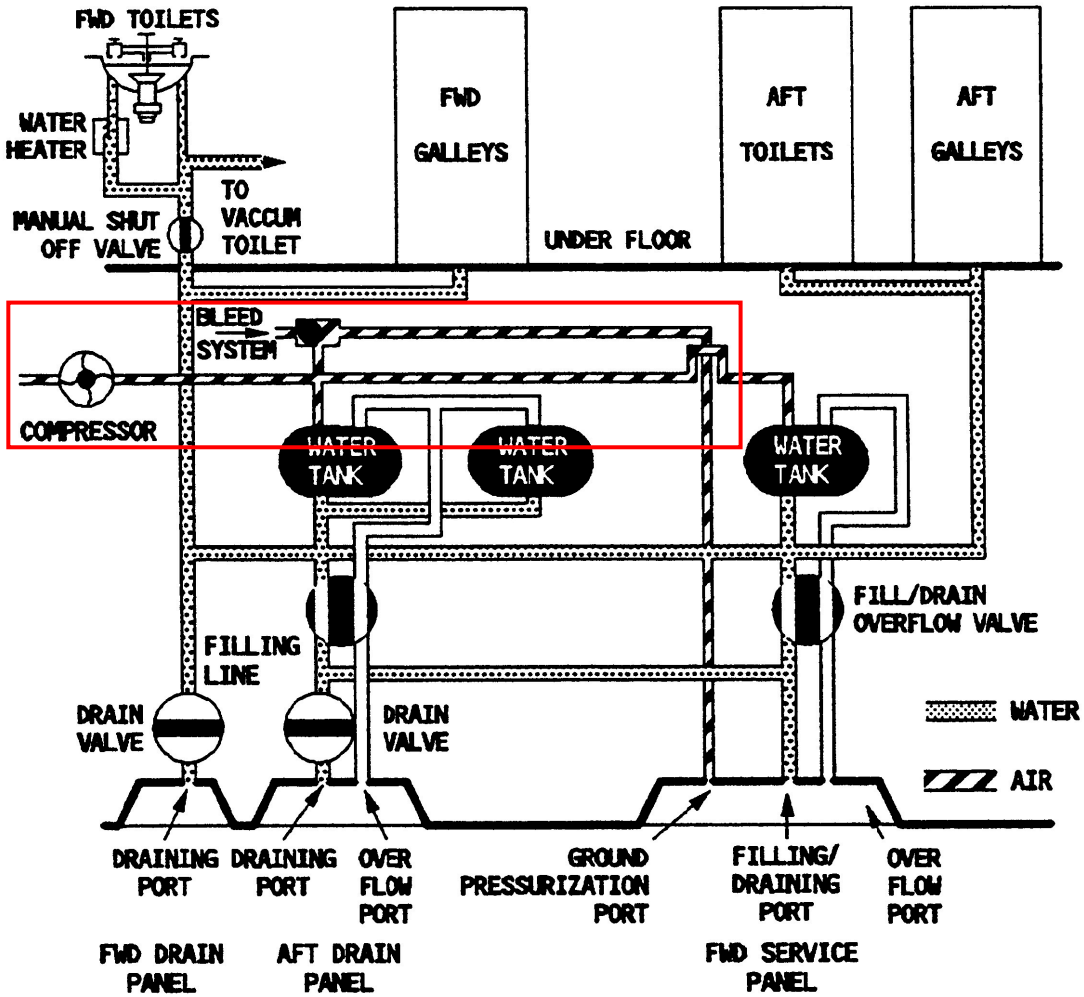
Aircraft Systems Investigated - Cabin Air Distribution





GENFAM A320: Cabin Air Distribution

Aircraft Systems Investigated - Potable Water System

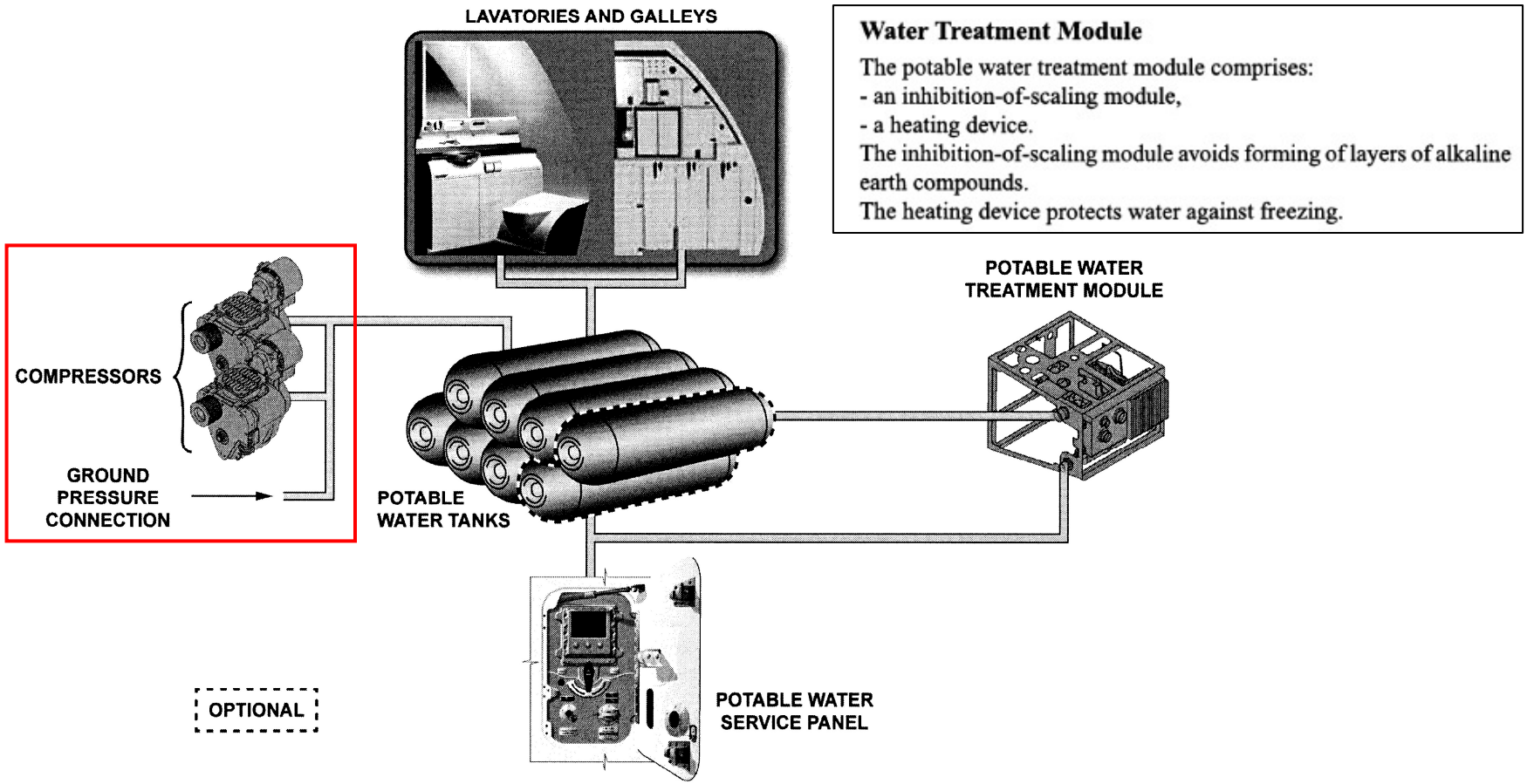


FCOM A340: Potable Water System Description

Aircraft Systems Investigated - Potable Water System

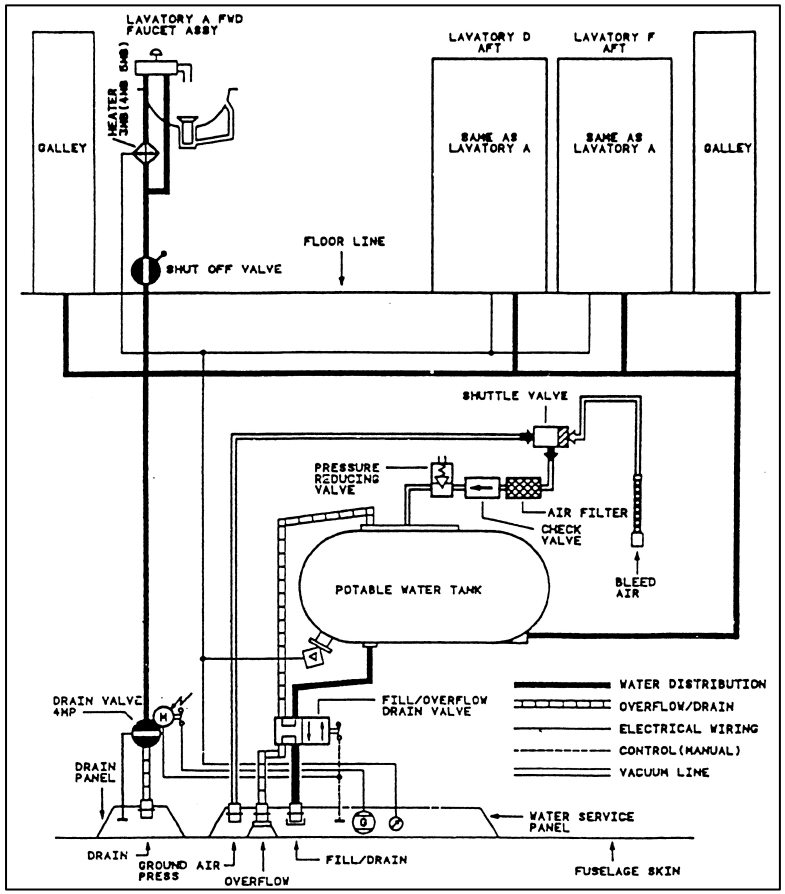
AIRBUS
Training & Flight Operations Support and Services

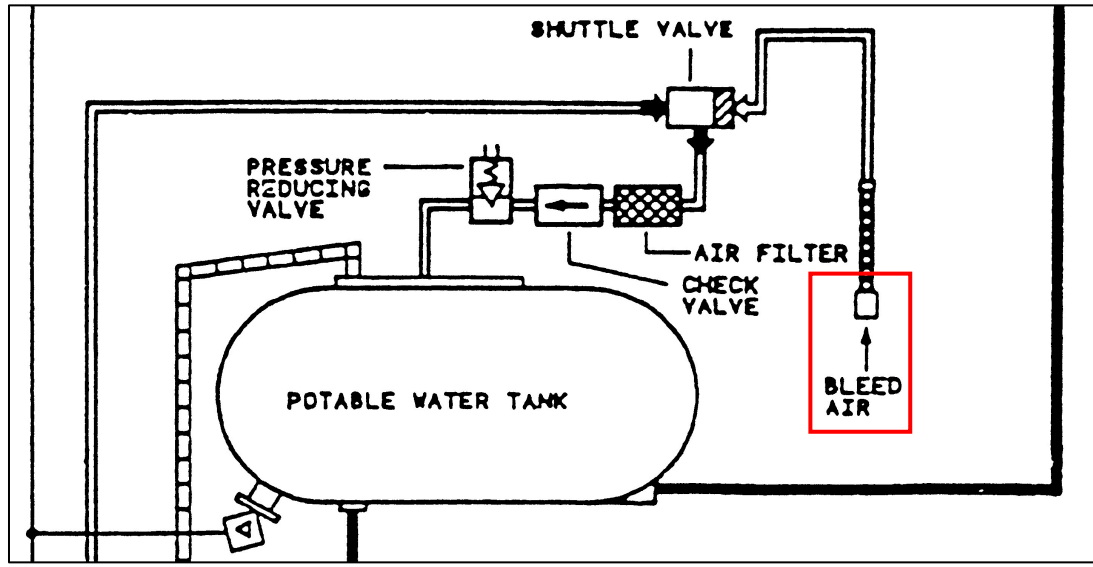
A380 TECHNICAL TRAINING MANUAL



A380

Aircraft Systems Investigated - Potable Water Tank Pressurization



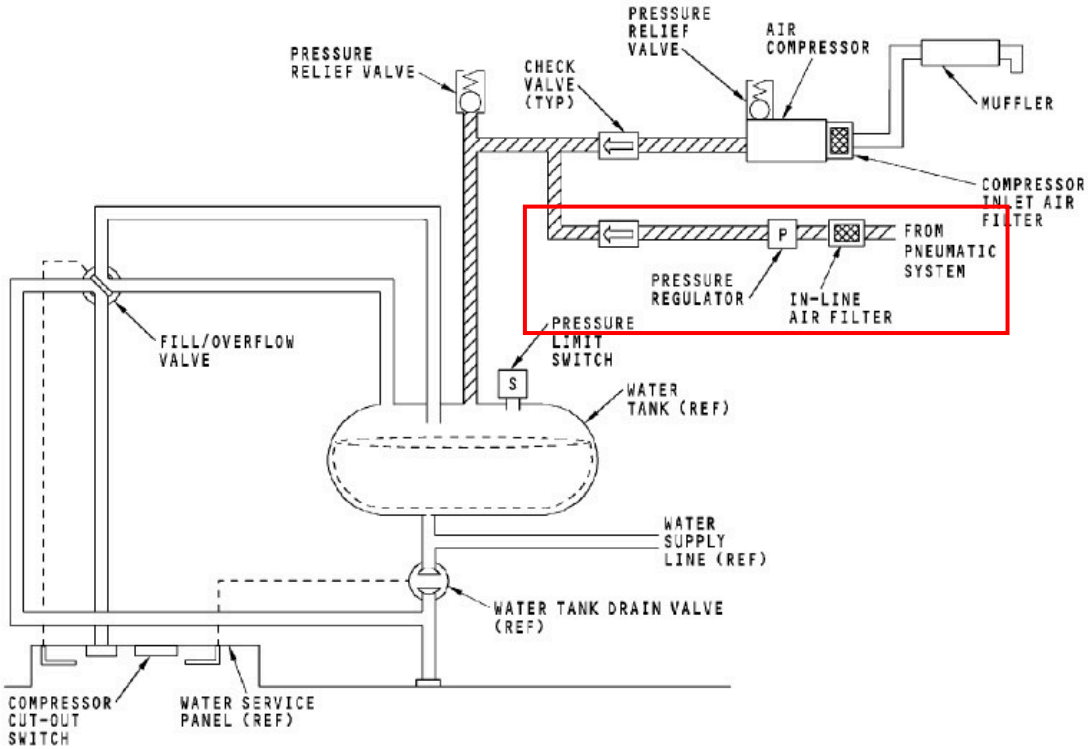


Training Material A320: Potable Water System pressurization.

Aircraft Systems Investigated - Potable Water Tank Pressurization

BOEING

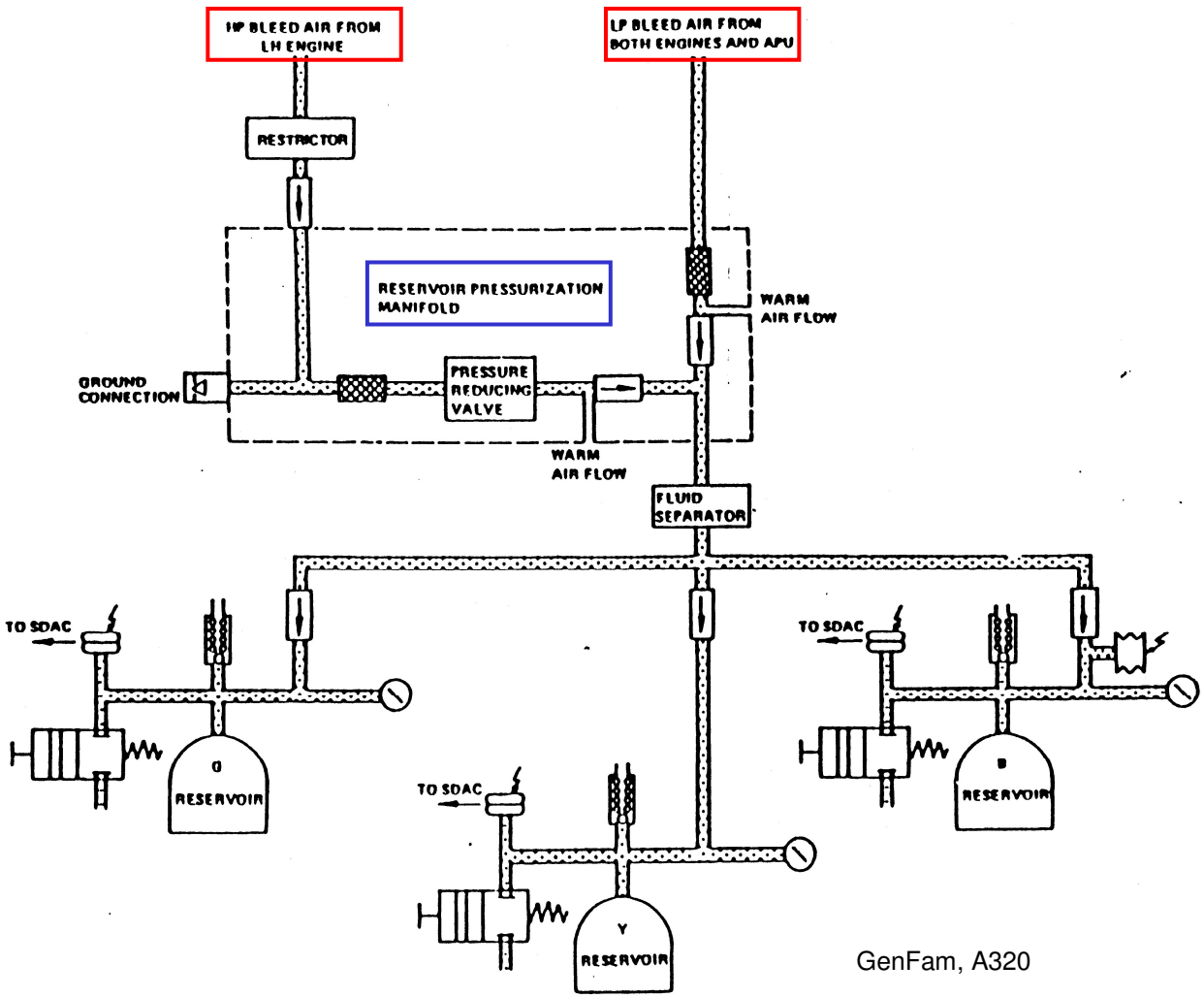
737-600/700/800/900 AIRCRAFT MAINTENANCE MANUAL



- 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 - Hydraulic Reservoir Pressurization

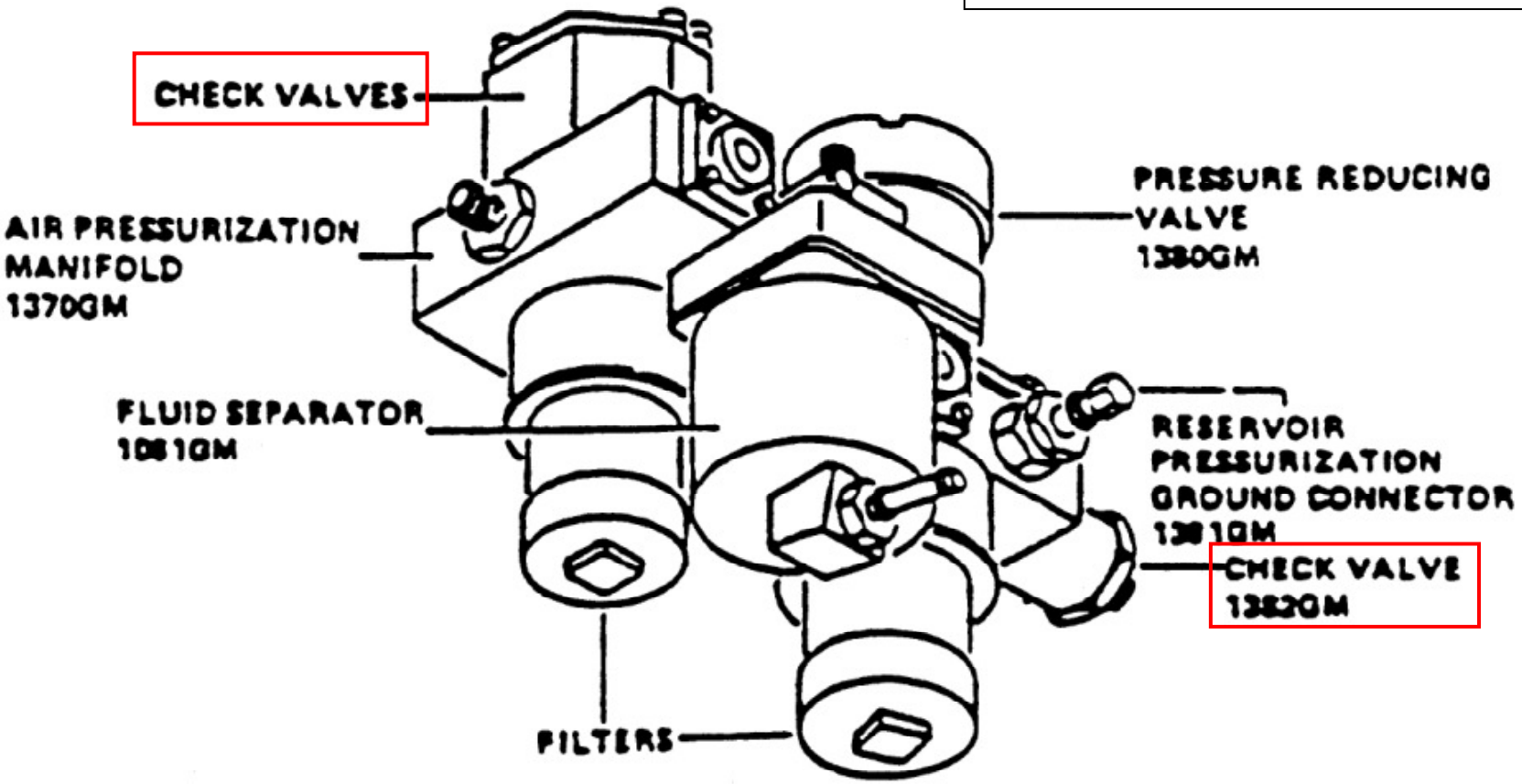


GenFam, A320

- 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.

Aircraft Systems Investigated - Hydraulic Reservoir Pressurization

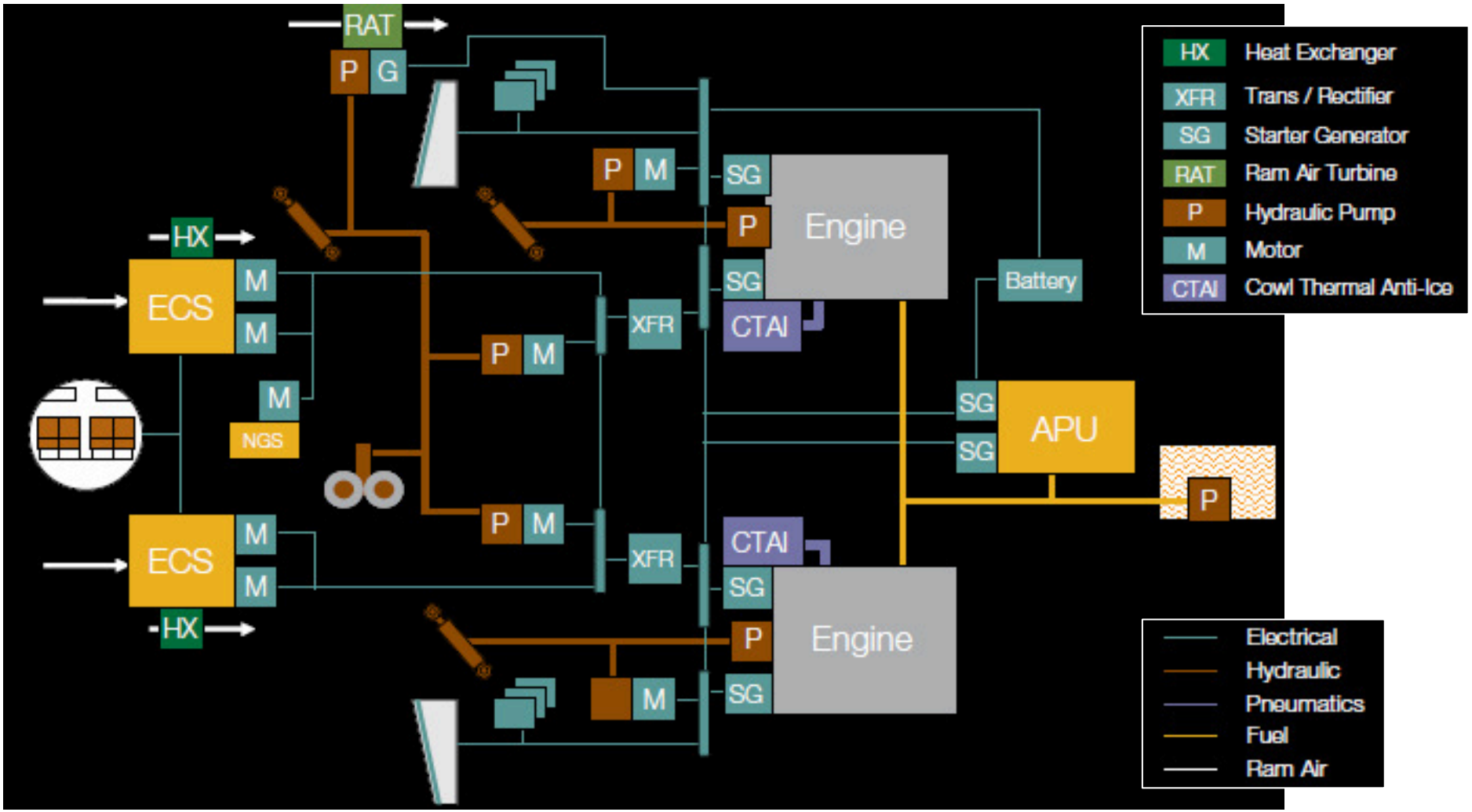
Reservoir Pressurization Manifold



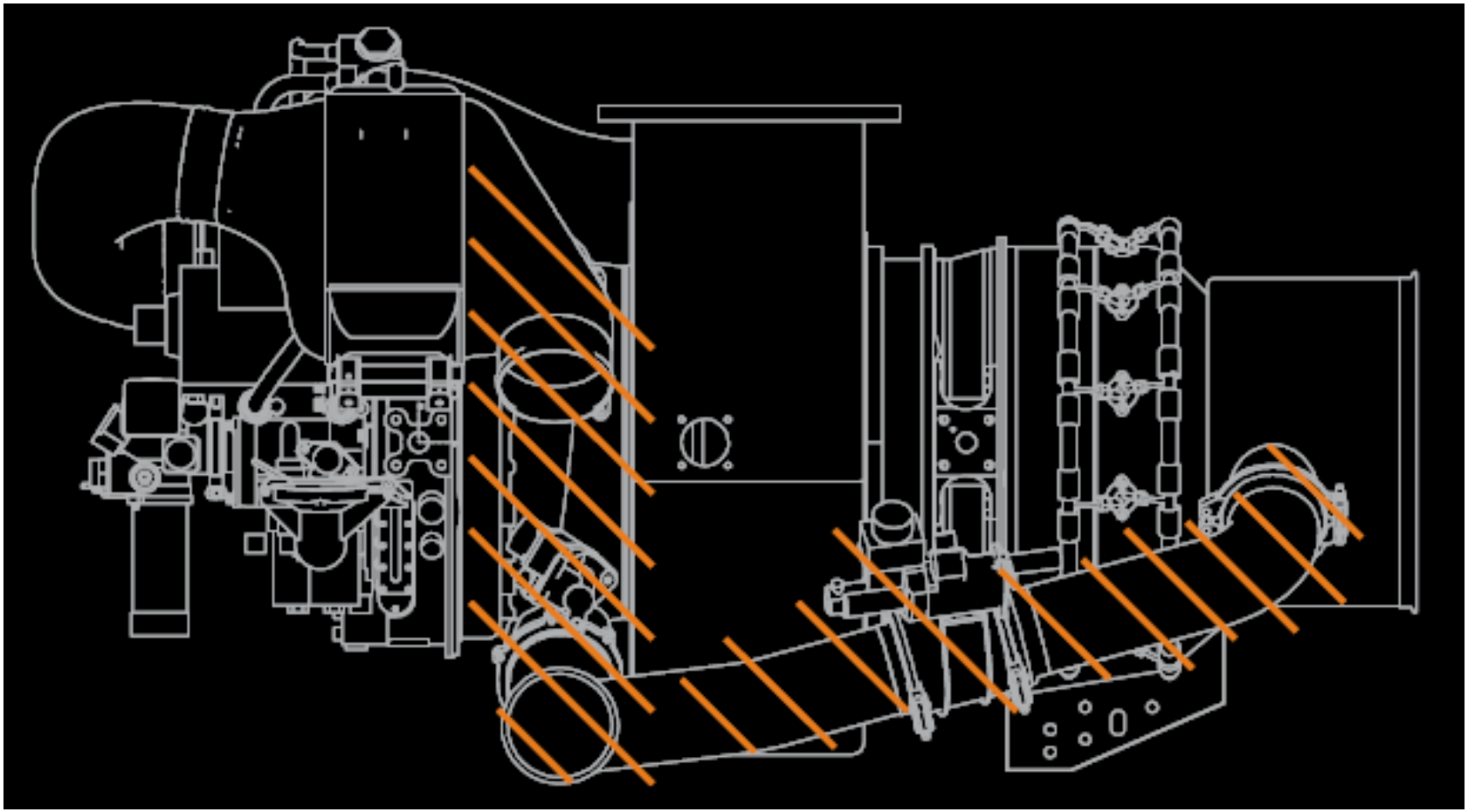
GenFam, A320

Aircraft Systems Investigated - Bleedless B787

Boeing: AERO



Aircraft Systems Investigated - Bleedless B787: APU



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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: $dm_e/dt = S_e \cdot v \cdot \rho_{air}$, S_e: engine frontal area, v: aircraft speed
  - Estimate bleed flow into cabin: $dm_b/dt = dV_{pax}/dt \cdot n_{pax} \cdot \rho_{air,cab}$
  - **Calculate oil in cabin per flight hour**:

$$C_{cab} = C \cdot x_{oil} \cdot x_{b,up} \cdot dm_b/dt \,/\, [dm_e/dt \cdot 1/(BPR+1)]$$

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.
https://www.gov.uk/government/publications/cabin-air-quality-faq

Passenger numbers at UK airports to increase from **219 million** passengers in 2011 to …
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/223839/aviation-forecasts.pdf

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

P(health issue) = 244/219000000 ≈ $1 \cdot 10^{-6}$ allowed would be 10^{-5} …10^{-7} (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 1.3 Safety requirements for large aeroplane's systems ACJ No. 1 to 25.1309 (**ACJ-25**)

effect on aircraft and occupants	normal	nuisance	operating limitations emergency procedures	significant reduction in safety margins difficult for crew to cope with adverse conditions passenger injuries	large reduction in safety margins crew extended because of workload or environmental conditions serious injury or death of small number of occupants	multiple deaths, usually with loss of aircraft
category of effect	minor	minor	minor	major	hazardous	catastrophe
probability of a failure according to JAR 25 (per flight hour)	frequent 10^{0} ... 10^{-2}	frequent 10^{-2} ... 10^{-3}	reasonably probable 10^{-3} ... 10^{-5}	remote 10^{-5} ... 10^{-7}	extremely remote 10^{-7} ... 10^{-9}	extremely improbable $< 10^{-9}$

Contents

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 possilbe!

Think:
system boundaries
Think:
systems engineering

Contact

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http://www.ProfScholz.de