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AIRCRAFT DESIGN AND SYSTEMS GROUP (AERO)

Aircraft Cabin Air and Engine Oil – An Engineering Update

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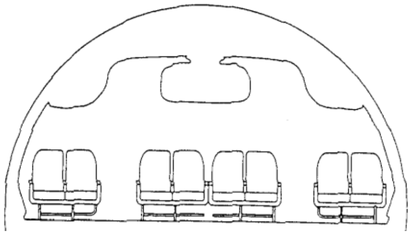
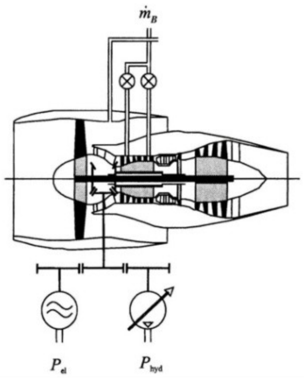
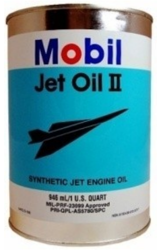






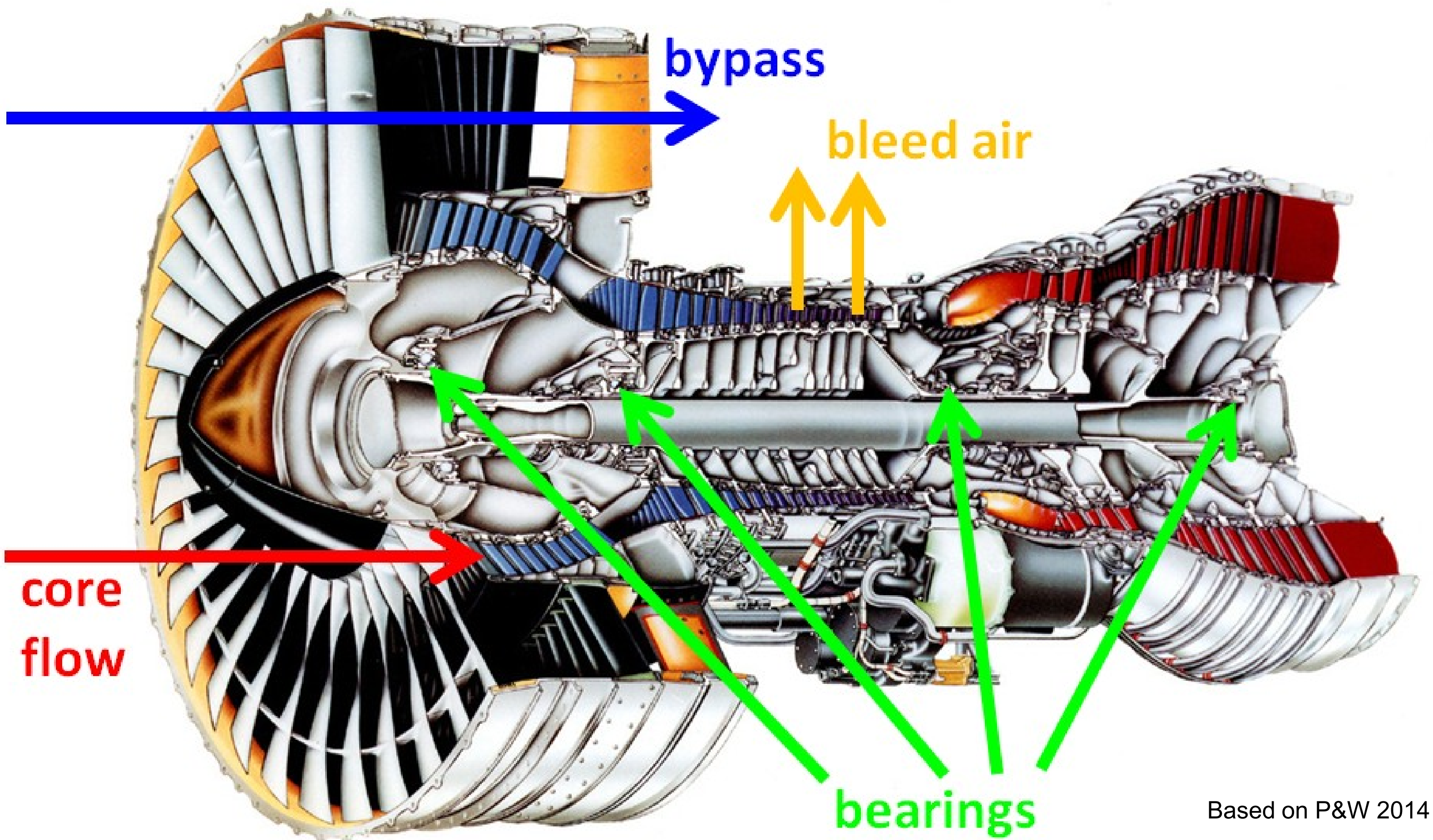
Abstract

Cabin air ventilation in passenger aircraft is done with outside air. At cruise altitude, ambient pressure is below cabin pressure. Hence, the outside air needs to be compressed before it is delivered into the cabin. The most economic system principle simply uses the air that is compressed in the engine compressor anyway and taps some of it off as "bleed air". The engine shaft is supported by lubricated bearings. They are sealed against the air in the compressor usually with labyrinth seals. Unfortunately, the jet engine seals leak oil by design in small quantities. The oil leaking into the compressor contains toxic additives. Furthermore, the oil includes toxic metal nanoparticles – normal debris from the engine. An alternative source for the compressed air is the Auxiliary Power Unit (APU). Like the aircraft's jet engine, it is a gas turbine, built much in the same way when it comes to bearings and seals. For this reason, also compressed air from the APU is potentially contaminated in much the same way. Compressed air from the engine is also used to pressurize the potable water. It has been observed that the potable water on board can also be contaminated. Fan air and bleed air ducts at the interface between engine and wing carry outside compressed air. The inside of the ducts shows differences. The brown stain in the bleed air duct appears to be engine oil residue. In comparison, the fan air duct is clean. This shows that oil leaves the compressor bearings. Ducting further downstream shows a black dry cover. The reason for the change in color seems to result from the different air temperatures: 400 °C at engine outlet and 200 °C further downstream behind the precooler. The water extractor is a part of the air conditioning pack. The inlet of the water extractor is covered with black oily residue, because the temperature is even lower at this point. The air conditioning air distribution ducts in the cabin are black inside from contaminated bleed air. New ducts are clean. Air duct are even clean inside at the end of the aircraft's life, in areas where they are used such that no bleed air flows through them. Flow limiters have been found in ducts of the air conditioning system that are clogged from engine oil. Also riser ducts feeding the cabin air outlets are black inside from engine oil residue. Cleaning on top of the overhead bins brings to light dirt that is clearly more than dust. The black residue known from the ducts settles also on the bin surface. Deicing fluid and hydraulic fluid can find their way into the air conditioning system via the APU air intake. A fence and a deflector around the air intake cannot fully prevent contaminants from entering the APU. Traces of contamination tend to be visible on the lower part of the fuselage. Contaminants are carried by the air flow in flight, from the landing gear bay to the APU inlet. Hydraulic systems are never leak free. A hydraulic seal drain system tries to collect hydraulic fluid leaving the system with partial success. It is impossible to catch all leaking hydraulic fluid. If the containers of the seal drain system are not emptied they spill over. In old aircraft, surfaces in the landing gear bay are covered with a layer of hydraulic fluid. Dirt accumulates on the sticky surface. The hydraulic fluid is not confined to the inside of hydraulic bays, but continues its journey on the lower side of the fuselage towards the APU. Deicing fluid if applied in the winter to the aircraft and can leak from the tail into the APU inlet. Fuel and oil also leak down onto the airport surfaces. These fluids can be ingested by the engine from the ground and can enter the air conditioning system from there. Entropy is the law of nature that states that disorder always increases. This is the reason, why it is impossible to confine engine oil and hydraulic fluids to their (predominantly) closed aircraft systems. This is why engine oil with metal nanoparticles hydraulic fluids, and deicing fluids eventually go everywhere and finally into the human body.

Contents

Jet Engine Technology & Results

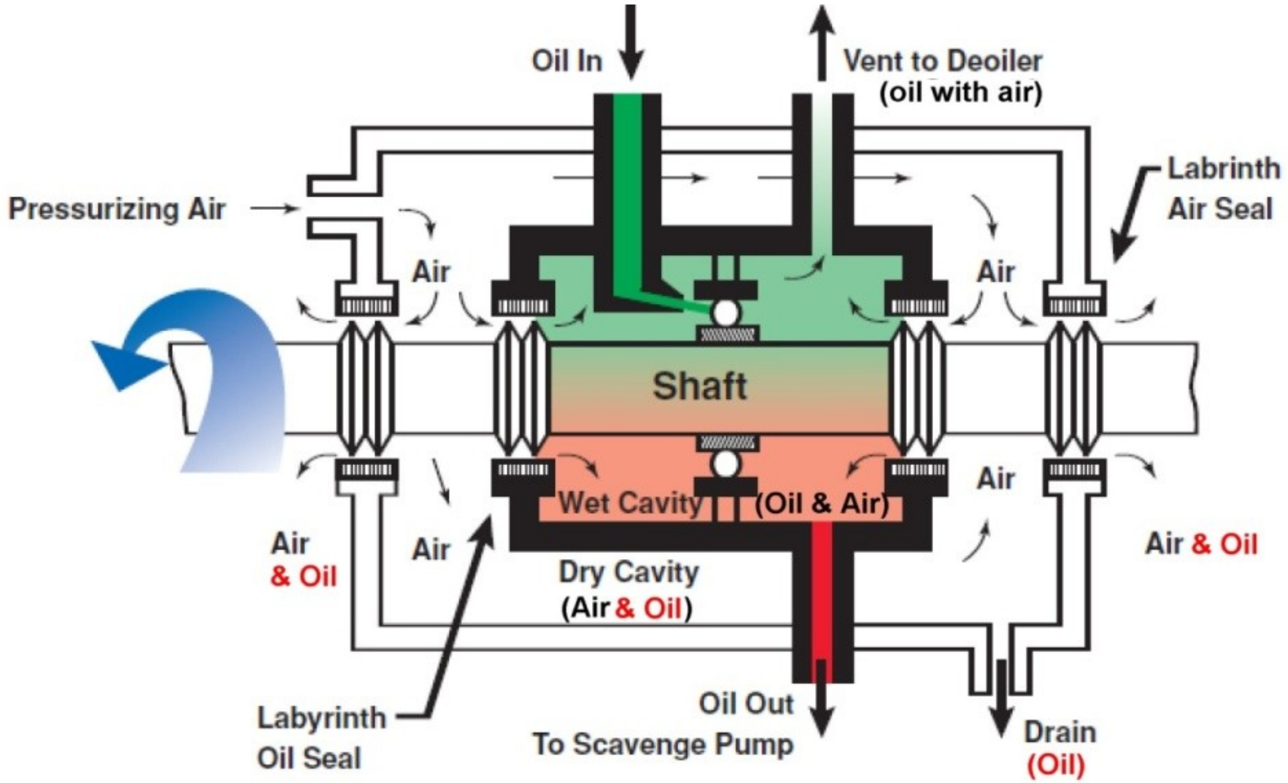
Engine Bearings and Bleed Air



Based on P&W 2014

Jet Engine Technology & Results

Lubrication and Sealing of Engine Bearings



Based on Exxon 2017

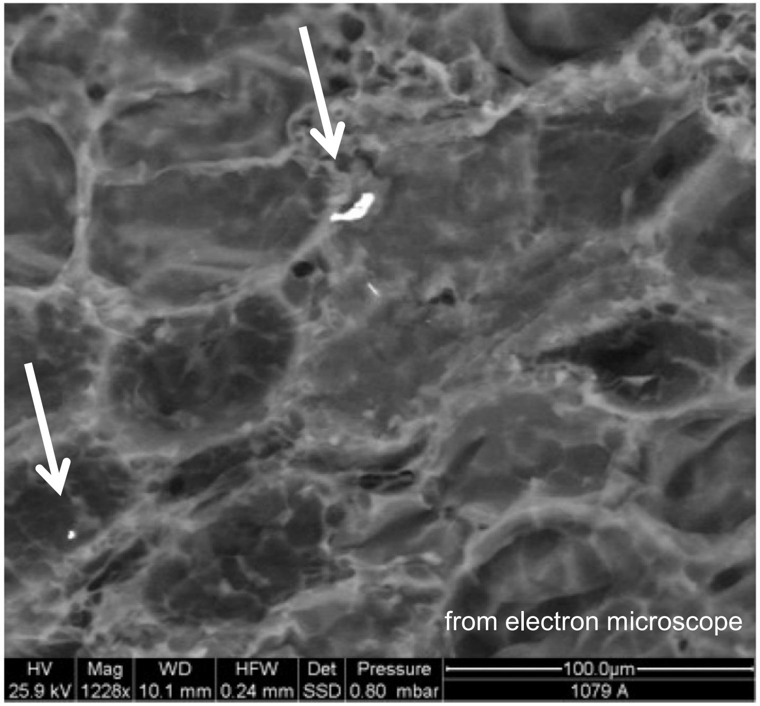
Normal operation of engine seals:

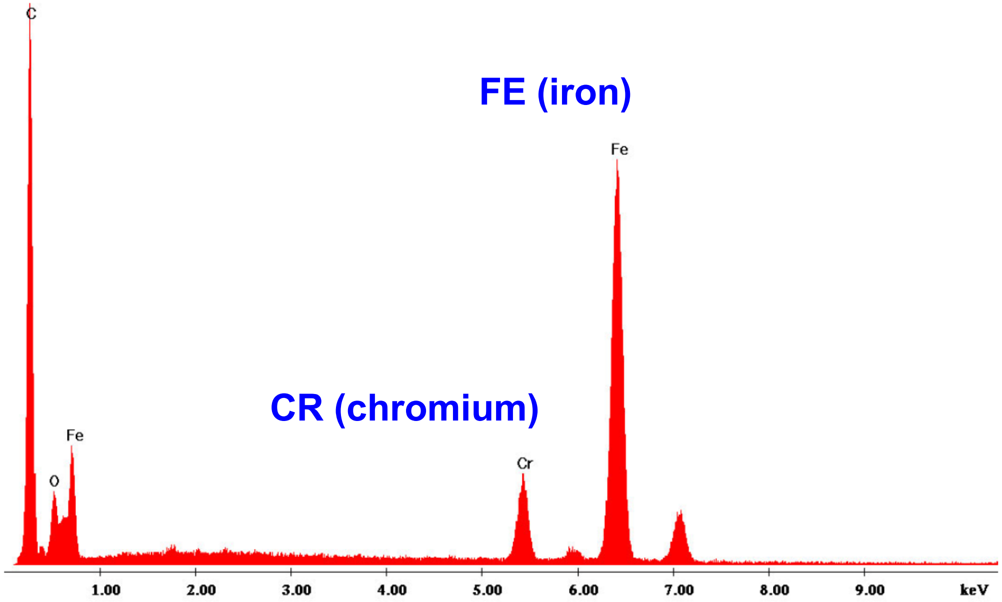
1. The "**drain**" discharges **oil**.
2. The "**dry cavity**" contains **oil**.
3. Air and **oil** leak from bearings **into** the **bleed air**.

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

Metal Nanoparticles in the Oil – Finally in Human Fatty Tissue of Aviation Employees

(Gatti 2019, report written for client)



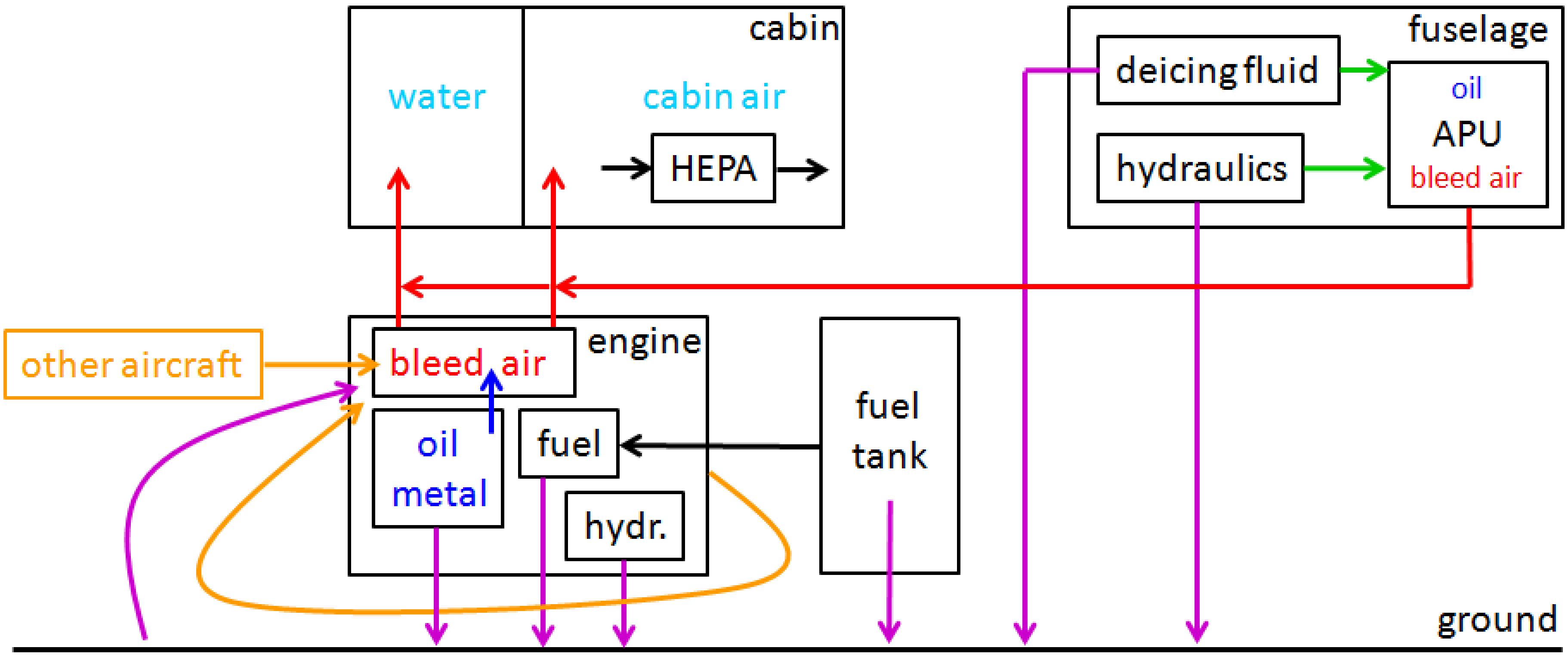


Analysis 8 of Table I. High-magnification image (1228x) and EDS spectrum of 10-micron and 1-micron brighter-looking particles composed of Carbon, Iron, Chromium and Oxygen: a stainless-steel composition. EDS: Energy-Dispersive X-ray Spectroscopy.

Distribution of Engine Oil with Metal Nanoparticles

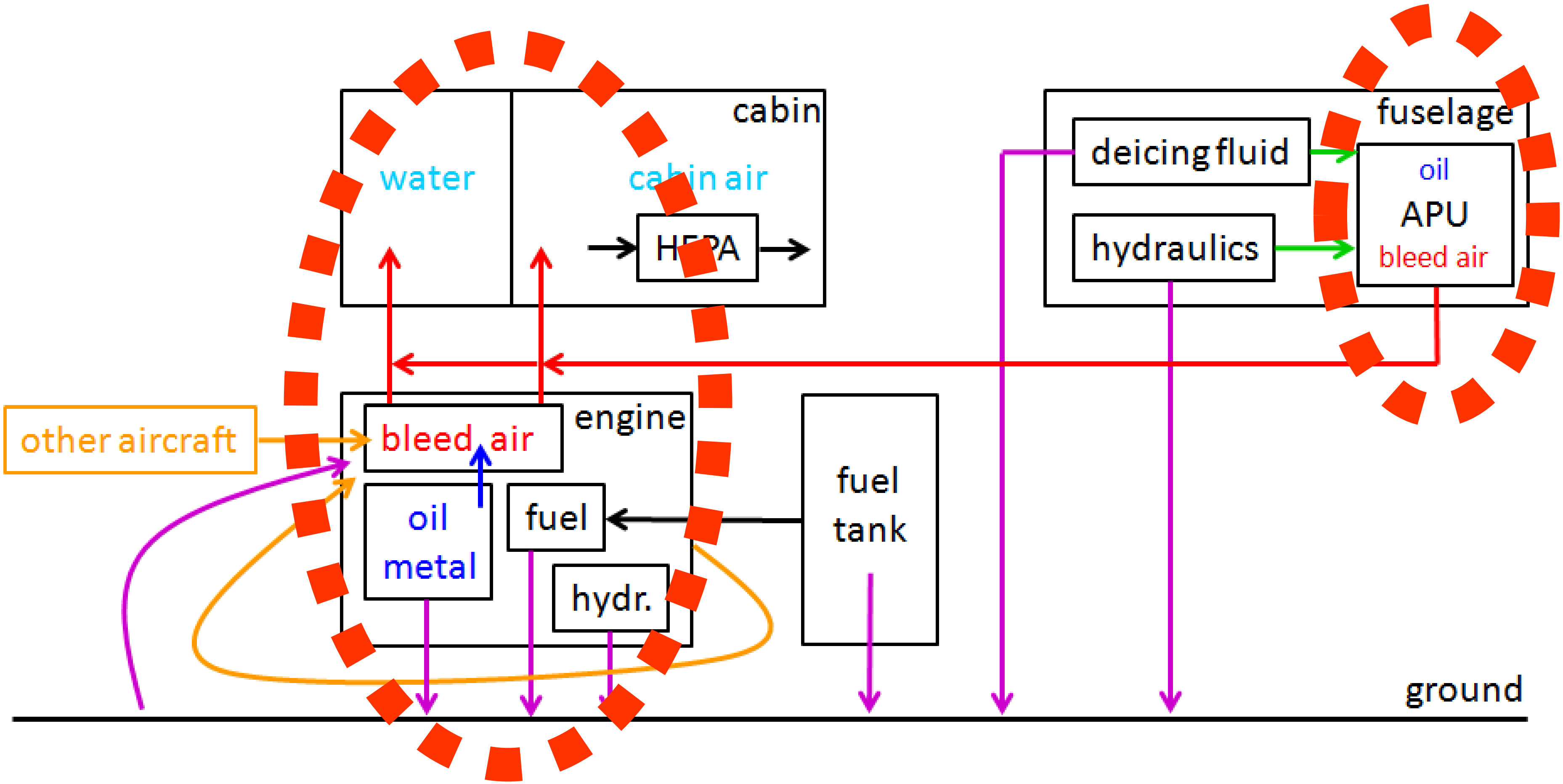
Distribution of Engine Oil with Metal Nanoparticles

Contaminants and Their Routes Into the Cabin



Distribution of Engine Oil with Metal Nanoparticles

The Route of Engine Oil Into the Cabin



Distribution of Engine Oil with Metal Nanoparticles

Cabin Air Contamination Event Due to Engine Oil After Technical Fault

Top: 2010-09-17, US Airways US-432, Boeing 757-200. Bottom: 2018-12-10, Indigo flight 6E-237, Airbus A320neo.

Distribution of Engine Oil with Metal Nanoparticles

Cabin Air Contamination Event Due to Engine Oil After Technical Fault

Top:2019-08-22, Hawaiian Airlines HA47, A321neo. Bottom: 2019-08-05, British Airways BA-422, Airbus A321.

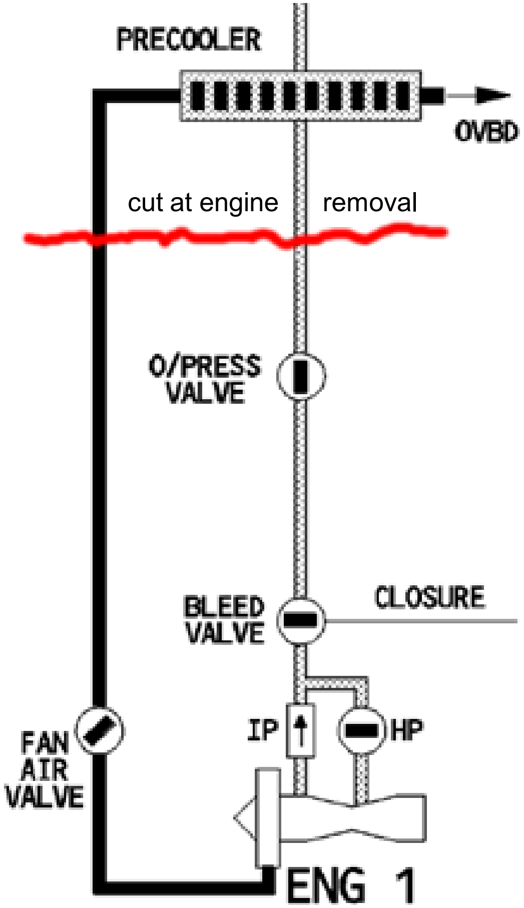
Engine Oil in the Potable Water

Potable water contaminated by bleed air on an Airbus A320. The last water extracted from the tank before it is empty is black, probably from engine oil residue.

Picture source:
Video: https://youtu.be/dlPOeudTTCI.
The video explained:
https://purl.org/CabinAir/WaterContamination.

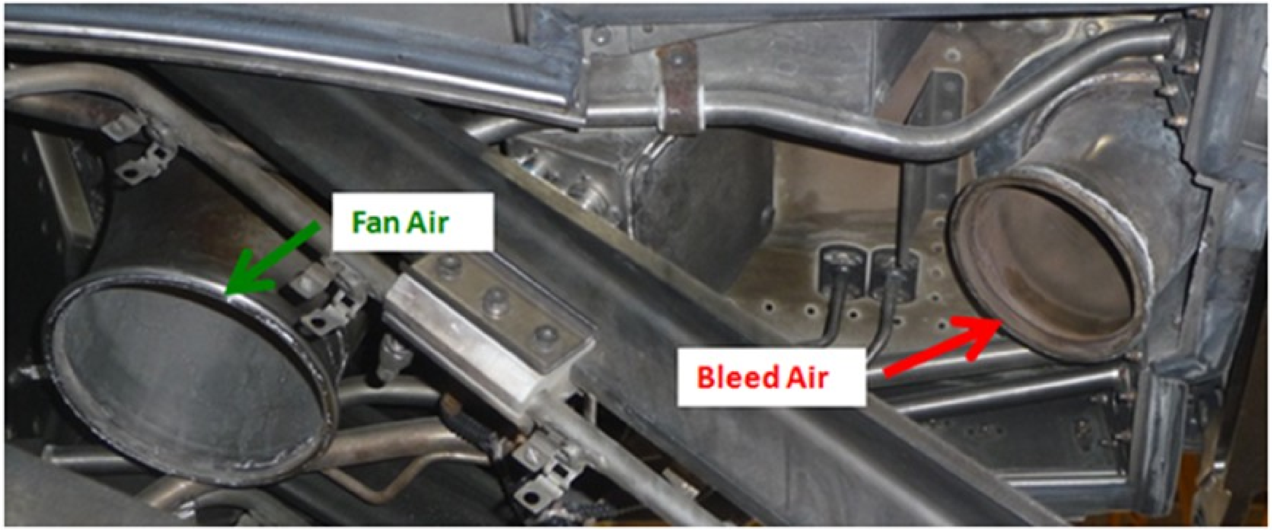
Distribution of Engine Oil with Metal Nanoparticles

Engine Oil Colors Bleed Air Duct Brown



Airbus A320 FCOM

Fan air and bleed air ducts at the interface between engine and wing on an Airbus A320. The brown stain in the bleed air duct appears to be engine oil residue. In comparison, the fan air duct is clean. Air temperature in the bleed air duct about 400 °C.



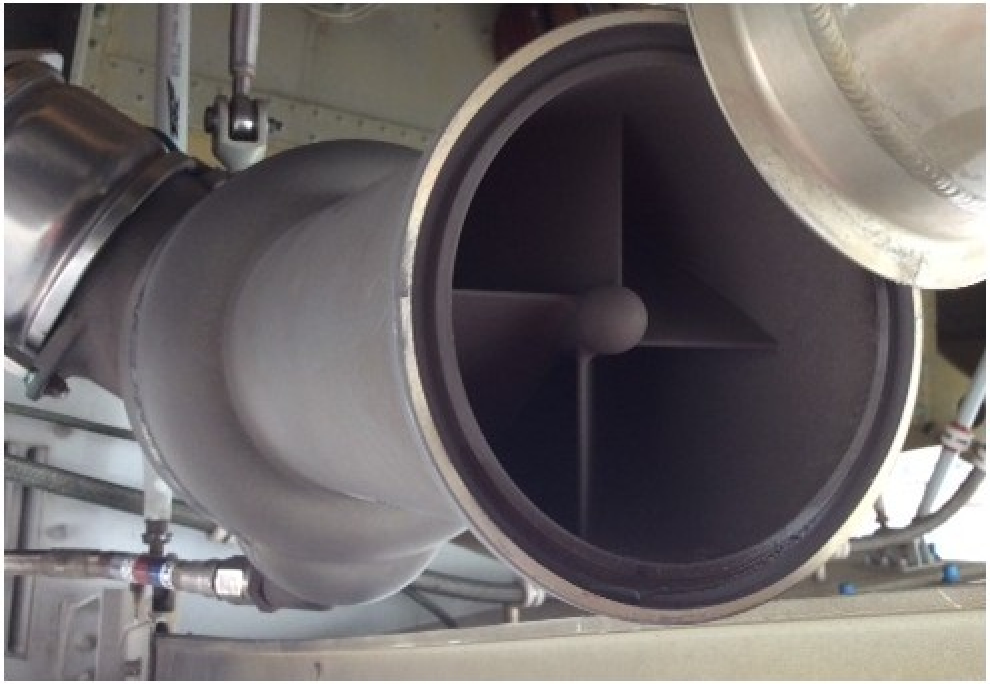
Distribution of Engine Oil with Metal Nanoparticles

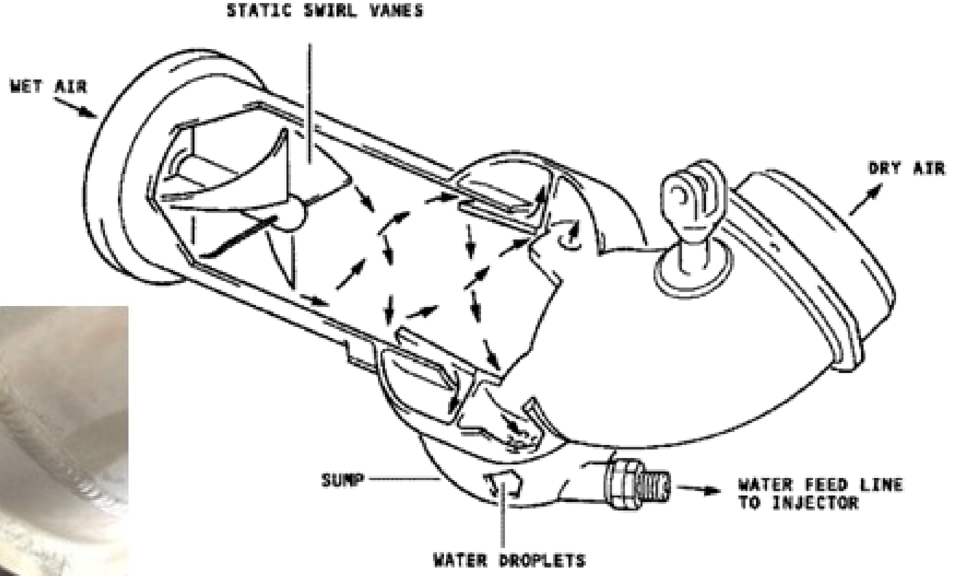
Engine Oil Colors Bleed Air Duct Black

Bleed air duct of a Boeing 737 with black oil residue inside. Air temperature of about 200 °C.

Picture source: **Video**: https://vimeo.com/groups/617439/videos/345959025

Engine Oil Residue Accumulates in Water Extractor





The Airbus A320 water extractor (Airbus 1999), is a part of the air conditioning pack. The inlet of the water extractor is covered with black oily residue.

Distribution of Engine Oil with Metal Nanoparticles

Engine Oil Colors Cabin Air Duct Black

Airbus A320 air conditioning air distribution duct in the cabin. The inside is black from contaminated bleed air.

Air Duct Is Clean at End of Life of an Aircraft, if Not Fed With Bleed Air

The inside of the air extract duct (located near the extract fan) is clean at the end of life of an Airbus A320, because the duct is normally not fed with bleed air.

Distribution of Engine Oil with Metal Nanoparticles

Engine Oil Colors Cabin Air Duct Black

Left: A unused duct supplied new.
Right: A ducts that had been installed downstream of the environmental control system air conditioning packs on a BAe 146 passenger aircraft after 26061 flight hours (CAA 2004).

Distribution of Engine Oil with Metal Nanoparticles

Flow Limiter in Air Conditioning Ducts Clogged

Flow limiter clogged from pyrolysed engine oil in ducts of the air conditioning system of Boeing 757 aircraft with Rolls-Royce RB211-535E4 engines operated by Icelandair (Hansen 2019) compared to a clean flow limiter (top).

Distribution of Engine Oil with Metal Nanoparticles

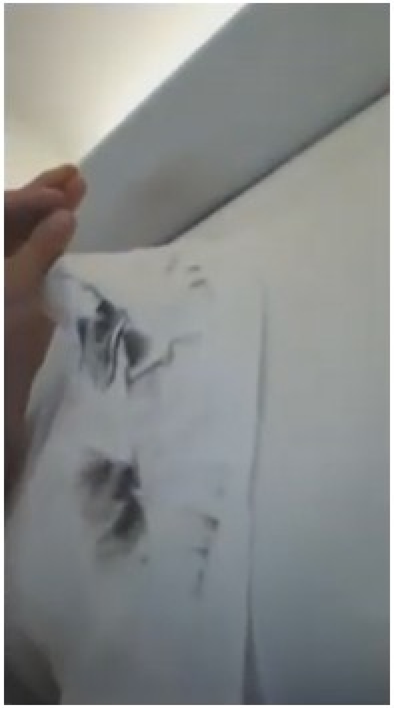
Engine Oil Colors Riser Ducts Black

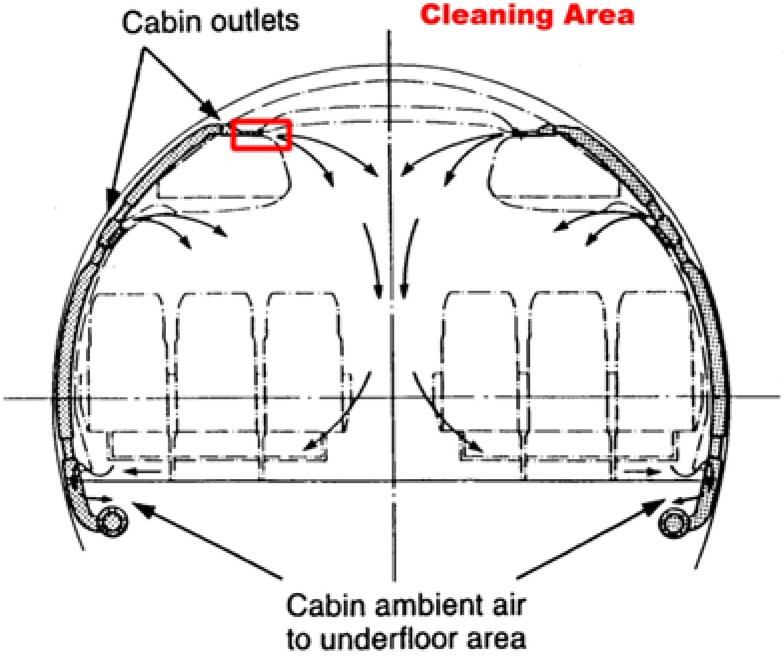
Video: https://bit.ly/2YXcL3a

Riser ducts and lower cabin air outlet on an Airbus A320 aircraft. The red line close to the cabin floor shows, where the duct was separated and opened. It is black inside from engine oil residue.

Distribution of Engine Oil with Metal Nanoparticles

Black Residue Settles on the Overhead Bin's Surfaces



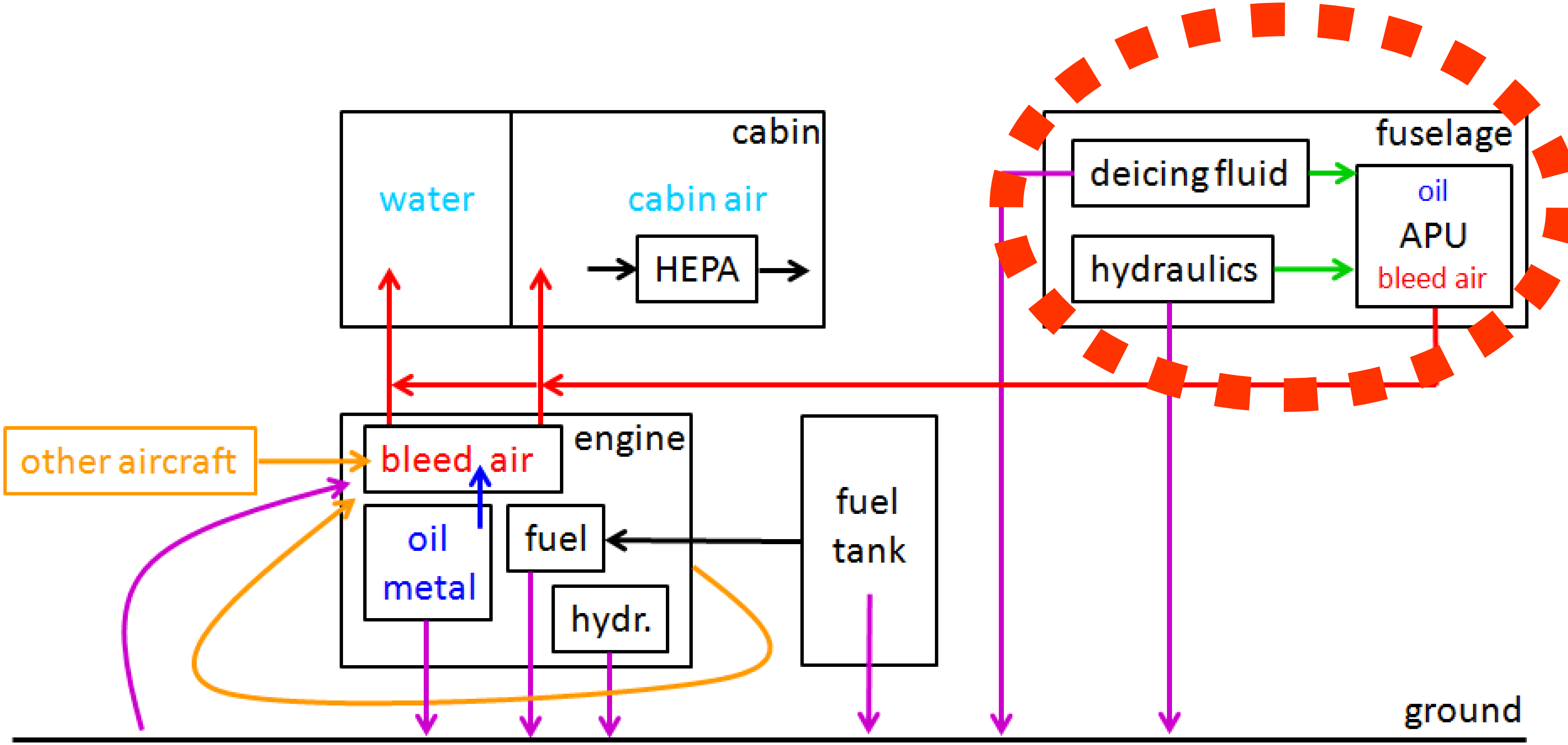


Left: Cleaning on top of the overhead bins of an Airbus A320 brings to light dirt that is clearly more than dust. The black residue known from the ducts settles also on the bin surface. Picture source: **Video**: https://youtu.be/uQfA_DiMBS8
Right: Airbus A320 cabin cross section with the upper cabin air outlet releasing potentially contaminated air on top of the overhead bins (Airbus 1999).

Distribution of Hydraulic and Deicing Fluid

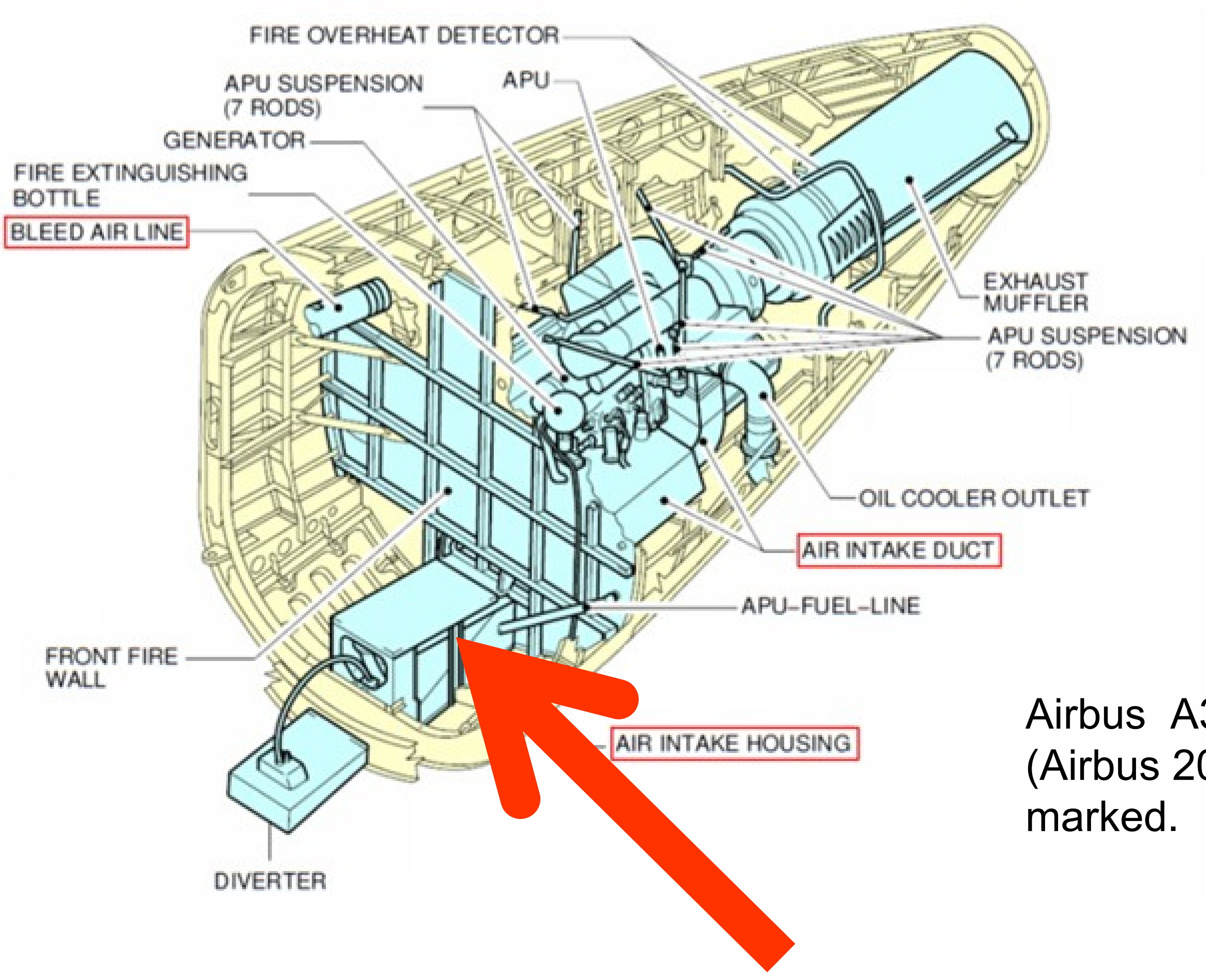
Distribution of Hydraulic and Deicing Fluid

The Route of Hydraulic and Deicing Fluid into the Cabin



Distribution of Hydraulic and Deicing Fluid

APU Air Intake – Entry Point for Hydraulic and Deicing Fluid into the Cabin



Airbus A320 APU installation (Airbus 2020). The air intake is marked.

APU Air Intake – Entry Point for Hydraulic and Deicing Fluid into the Cabin

Left: Air intake of the A320 APU. Fence and deflector around the APU air intake are clearly visible. These measures cannot fully prevent contaminants from entering the APU. Right: Traces of contamination are clearly visible on the lower part of the fuselage. Carried by the air flow in flight, the contaminants reach the APU inlet. Source of picture on the right: Airbus 2019.

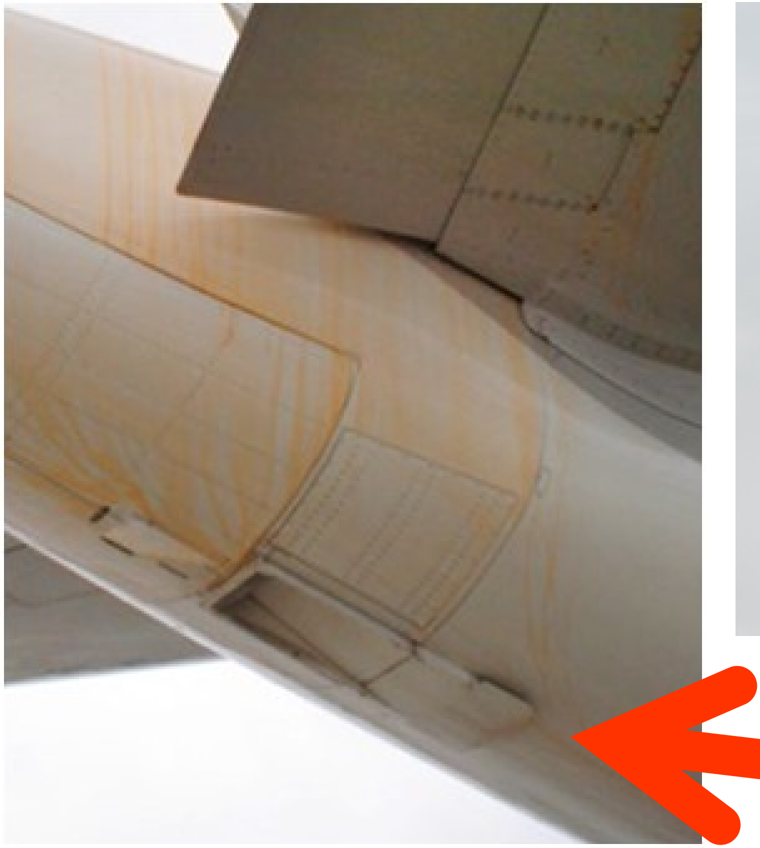
Distribution of Hydraulic and Deicing Fluid

"Zero Leakage" of Hydraulic Systems Has Not Been Achieved

Mekanikong 2019a

Aft collector tank of the A320 hydraulic seal drain system. In this old Airbus A320, **all surfaces** in the landing gear bay **are covered with a layer of hydraulic fluid**. Dirt accumulates on the sticky surface. The hydraulic fluid is not confined to the inside of the hydraulic bay, but continues its journey on the lower side of the fuselage towards the APU inlet (previous page).

Deicing Fluid Leaks from the Tail into the APU Inlet

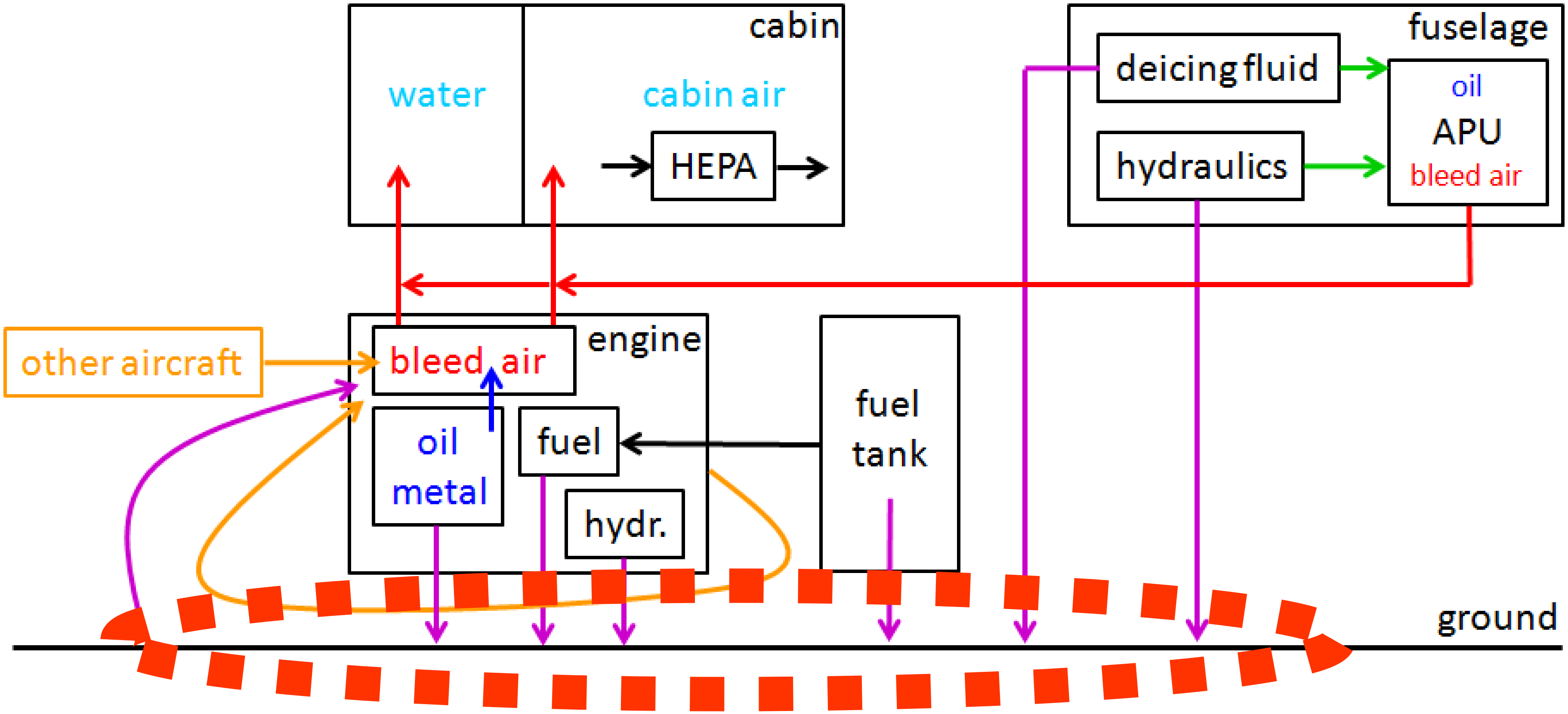


Vera-Barcelo 2013

Petchenik 2015

Distribution of Fluids via the Airport Surface

The Route of Fluids Down to the Ground and Back into the Engine



Leak Limits of Aircraft Equipment (Example)

INSPECT/CHECK	MAXIMUM SERVICEABLE LIMITS
Oil	
The starter pad	7 drops/min
The AGB rear hydraulic pump pad	7 drops/min
The AGB fuel pump pad	7 drops/min
The lube unit pad	No leaks allowed
The main oil/fuel heat exchanger	7 drops/min
The AGB/IDG pad	7 drops/min
The forward sump	20 drops/min
The Aft sump (flooding drain)	Any amount, less than 20 drops/min after engine shutdown.
The Aft sump area	No leak allowed
INSPECT/CHECK	**MAXIMUM SERVICEABLE LIMITS**
Fuel	
The fuel manifold shroud	No leaks allowed
Fuel pump at the AGB drive pad	60 drops/min (up to 90 drops/min allowed for 25 cycles)

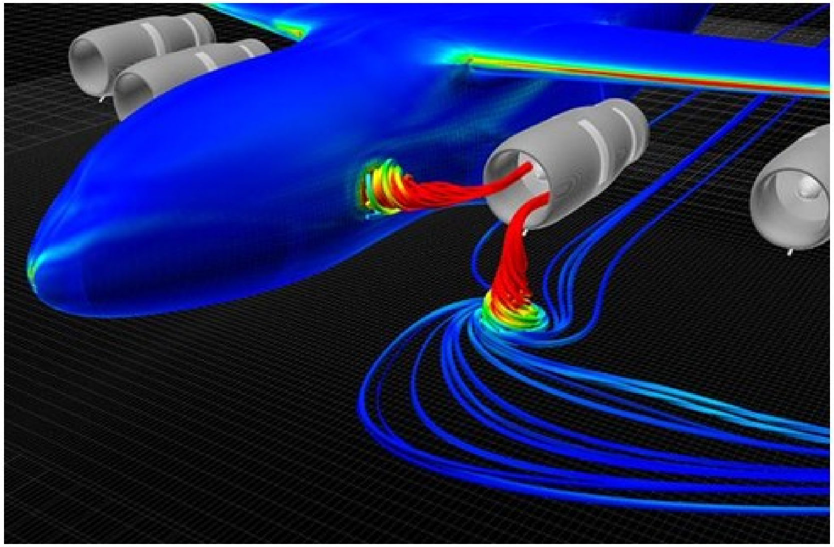
■ ■ ■

A320 leak limits for the CFM56-5B engine in drops per minute. Drops add up over time (Mekanikong 2019b).

AGB: Accessory Gearbox

Fluids Can Be Ingested by the Engine from the Ground

The ground vortex can also form between the ground and an engine on a high wing (Childs 2017).

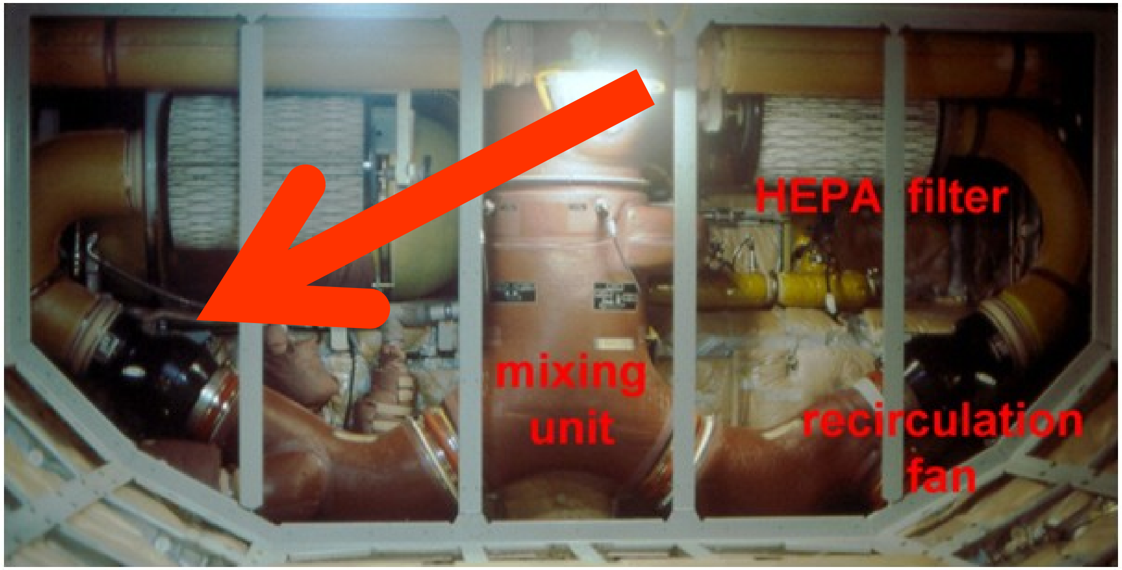


Simulation of two intake vortices, one of them as a ground vortex. The rotation of the vortex is visible (https://perma.cc/VH99-87XS).

More Contamination

More Contamination

Contaminated Recirculation Fan



The face of the recirculation fan of an Airbus A320 is covered by an oily back soft substance that can be scraped off with a screw driver. Picture source: **Video**: https://bit.ly/2YXcL3a

More Contamination

Contaminated Cargo Compartment Heating

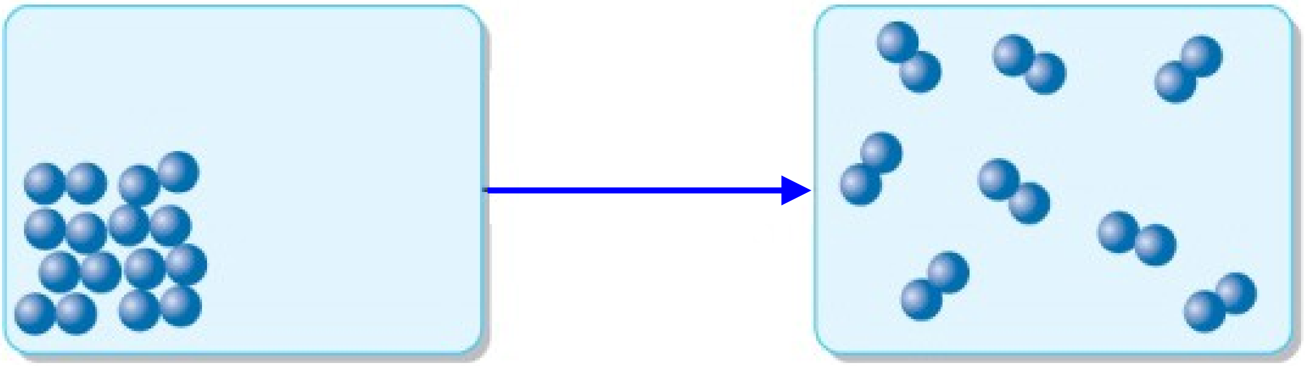
The ambient air inlet in the cargo compartment of the Airbus A320 for cargo compartment heating and ventilation. The inlet is full of moist dust.

Entropy – Distribution by Law of Nature

Entropy – Distribution by Law of Nature

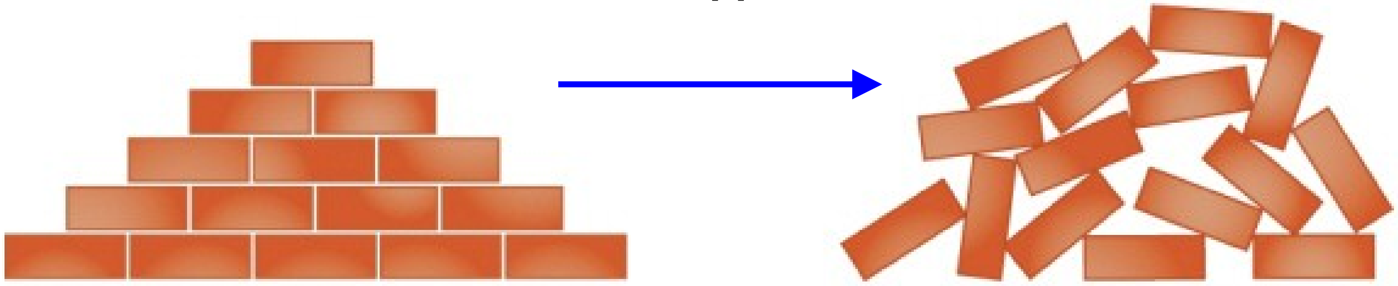
Contaminants Spread Everywhere

Gas spreads to fill space over time



Entropy (Disorder) Always Increases!

Pile of bricks dropped from a truck



Contaminants Spread Everywhere

Entropy is the law of nature by which ...

- **engine oil with metal nanoparticles**
- **hydraulic fluid**
- **deicing fluid**

goes everywhere and finally into the human body.

Contact

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References

A320 FCOM. Airbus: A320 – Flight Crew Operating Manual (FCOM)

AIRBUS, 1999. *A319/A320/A321 Aircraft Maintenance Manual (ADRES)* [CD]. Blagnac, France: Airbus Industrie, Customer Service Directorate.

AIRBUS, **2019**. *Digest for Smoke, Odors and Fumes (SOF): In Service Information*. Ref.: ISI 21.00.00139. Blagnac, France: Airbus.
Archived at: https://perma.cc/W3U7-C4HM

AIRBUS, **2020**. *A320 – Aircraft Characteristics Airport and Maintenance Planning*. AIRBUS S.A.S., Customer Services, Technical Data Support and Services, 31707 Blagnac Cedex, France. Issue: Sep 30/85, Rev: Dec 01/20.
Available from: https://bit.ly/37ctHaR (Aircraft Characteristics Homepage)
Archived at: https://perma.cc/ARS5-AN5P

CAA, 2004. *Cabin Air Quality*. Gatwick Airport, West Sussex, UK: Civil Aviation Authority (CAA). CAA PAPER 2004/04.
Available from: https://publicapps.caa.co.uk/docs/33/CAPAP2004_04.PDF
Archived at: https://perma.cc/MY6M-35Z5

CHILDS, Peter RN, **2017**. Jet Engine Internal Air Systems [Presentation]. In: *International Aircraft Cabin Air Conference 2017* (Imperial College London, 19.-20.09.2017).
Available from: https://doi.org/10.5281/zenodo.4501577

References

EXXON, **2017**. *Jet Engine Oil System, Part 2: Bearing Sump Lubrication*.
Available from: https://exxonmobil.co/2I6LNAV
Archived at: https://perma.cc/RL7E-5XUP

GATTI, Antonietta, M.; MONTANARI, Stefano, **2019**. *Evaluation of a Pathological Sample Through an Environmental Scanning Electron Microscopy Investigation and an X-Ray Micro-Analysis*. Report 3/2019. Nanodiagnostics, Via E. Fermi, 1/L, 41057 San Vito di Spilamberto (Modena), Italia. https://www.nanodiagnostics.it

HANSEN, Richard [Icelandair], **2019**. Suspected Air Quality Problems on Board - Experiences and Actions. In: *International Aircraft Cabin Air Conference 2019* (Imperial College London, 17/18.09.2019).
Available from: https://doi.org/10.5281/zenodo.4464537

MEKANIKONG, **2019a**: Hydraulic Aft Collector Tank. Facebook, 2019-06-11.
Archived at: https://perma.cc/YXM4-MTZR?type=image

MEKANIKONG, **2019b**: A320 Engine Leak Limits, CFM-56. Facebook, 2019-05-14.
Archived at: https://perma.cc/9SKM-88KU?type=image

PETCHENIK, Ian [Flightradar24], **2015**. *Ready for Winter – A Look at Aircraft Deicing*. Flightradar24 Blog.
Available from: https://www.flightradar24.com/blog/ready-for-winter-a-look-at-aircraft-deicing
Archived at: https://perma.cc/TGQ7-KXFM?type=image

VERA-BARCELO, Laura, **2013**. A Clean APU Means Clean Cabin Air. In: AIRBUS. *FAST #52: Airbus Technical Magazine*. 2013, August
Available from: https://bit.ly/341o5OT (Fast Homepage)
Archived at: https://perma.cc/5AW9-D5CW

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SCHOLZ, Dieter, 2018. Technical Solutions to the Problem of Contaminated Cabin Air. German Aerospace Congress, Friedrichshafen, Germany, 04.-06.09.2018. Presentation No. 0270.
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