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Aircraft Cabin Air and Engine Oil – Routes of Contamination

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Abstract

Purpose: This conference paper discusses potential contamination of the air in passenger aircraft cabins. It gives an overview of cabin air contamination basics. It further names possible contamination sources and possible routes of contamination.

Methodology: Evidence follows from a review of material found on the Internet and from the documentation of a visit to an aircraft recycling site. Parts were retrieved at the site and investigated later with more time.

Findings: Jet engine seals leak oil in small quantities. Metallic nanoparticles are found in the oil and have been detected in human fatty tissue of aviation workers. It has been observed that the potable water on board can also be contaminated. Oil traces have been found in bleed ducts, air conditioning components, and in air conditioning ducts. Deicing fluid and hydraulic fluid can find their way into the air conditioning system via the APU air intake. 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 can go everywhere and finally into the human body.

Research Limitations: No measurements have been made.

Practical Implications: Awareness and prevention of contaminated cabin air can protect passengers and crew.

Social Implications: The exposure of contaminated cabin air provides a basis for a general discussion and shows that people should be alerted and need to act. New technologies need to be implemented such as a bleed free architecture.

Originality: This paper shows probably more images with parts upstream of the engine compressor contaminated by leaking engine oil than any previous publication.

Keywords

aircraft, passenger, cabin, engine, bearing, lubrication, oil, seal, compressor, hydraulic, deicing, fluid, bleed air, contamination, ventilation, APU, ingestion, air conditioning, entropy, fume event, CACE

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1 Introduction

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 and taps some of it off as "bleed air". This principle is explained in Scholz 2014a (German) and Scholz 2018 (English). In the context of contaminated cabin air the background can be found in Scholz 2017a, Scholz 2017b, and Scholz 2019. **Figure 1** shows the contaminants and their routes into the cabin. The individual routes are explained below.

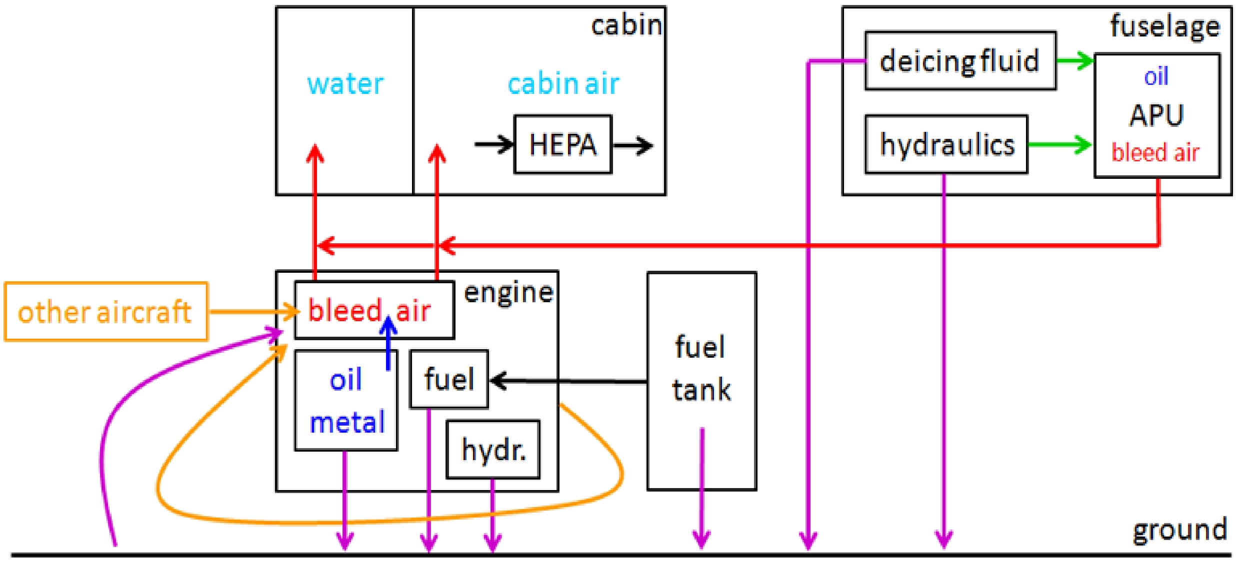

Figure 1 Contaminants and their routes into the cabin.

Route in blue: Seals at the engine bearings leak by design (Chapter 2). The leaking oil includes metal nano particles (Chapter 3). The oil with metals finds its way into the engine compressor. The same holds for the APU.

Routes in green: Deicing fluid sprayed on the tail of the aircraft flows down along the surface of the aft fuselage and surrounds the air intake of the APU at the bottom of the fuselage. Hydraulic fluid leaks from the main landing gear bay and is directed along the outside of the fuselage, to the APU air intake. In this way deicing fluid and hydraulic fluid can enter the APU via its air intake (Chapter 4).

Routes in red: Oil and metal from the engines find their way via bleed air into the cabin (Chapter 3) and into the potable water (Chapter 3.1). Oil leaks also from the APU into the APU bleed air and into the cabin. In addition, deicing fluids and hydraulic fluids make their way via the APU bleed air into the cabin.

Routes in purple: Deicing fluids, hydraulic fluids, oil, and fuel (from the fuel tank or from the engine) drip on the ground. The engine ingest these liquids from the ground (Chapter 5). Once in the engine compressor, the liquids find their way via the bleed air into the cabin.

Routes in orange: Exhaust gases from other aircraft are ingested. In case of a strong tailwind on the ground or in case of reverse thrust at landing, the engine ingests its own exhaust. Contaminates find their way via the bleed air into the cabin.

HEPA filter: In the cabin, HEPA filter are part of the recirculation (Chapter 6). Standard HEPA filters cannot mitigate the problem of oil contamination.

2 Jet Engine Technology and Results

The engine shaft is supported by lubricated bearings. **Figure 2** shows the location of the bearings in a jet engine and the position, where the bleed air is tapped off for cabin ventilation.

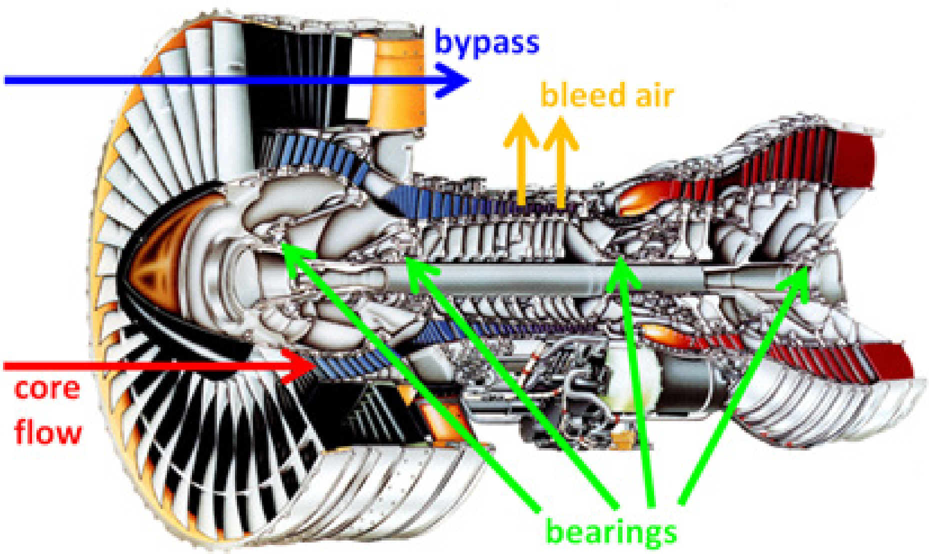

Figure 2 Engine bearings and bleed air (based on P&W 2014).

The bearings are sealed against the air in the compressor usually with labyrinth seals, shown in **Figure 3**. Unfortunately, the jet engine seals leak oil by design in small quantities. Even more so, the seals leak oil in certain flight phases, when they are worn out, or in failure cases.

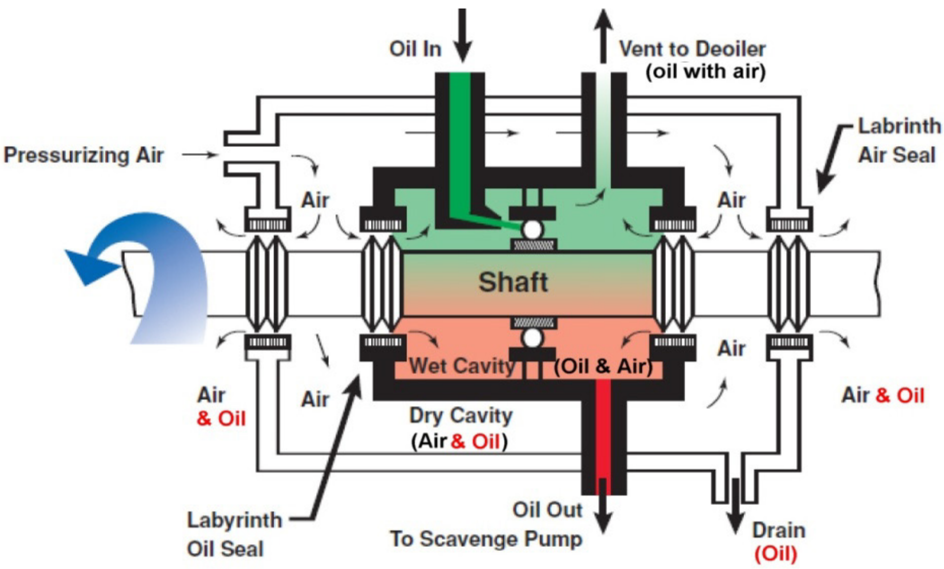

Figure 3 Lubrication and sealing of engine bearings (based on Exxon 2017).

Even in normal operation, the engine seals leak small quantities of oil. This follows from **Figure 3** and these observations:

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

Accordingly, engines leak small amounts of oil by design. The oil leaking into the compressor contains toxic additives. Furthermore, the oil includes toxic metal nanoparticles – normal debris from the engine. These metal nanoparticles in the oil are finally proven in human fatty tissue of aviation employees as shown in **Figure 4**.

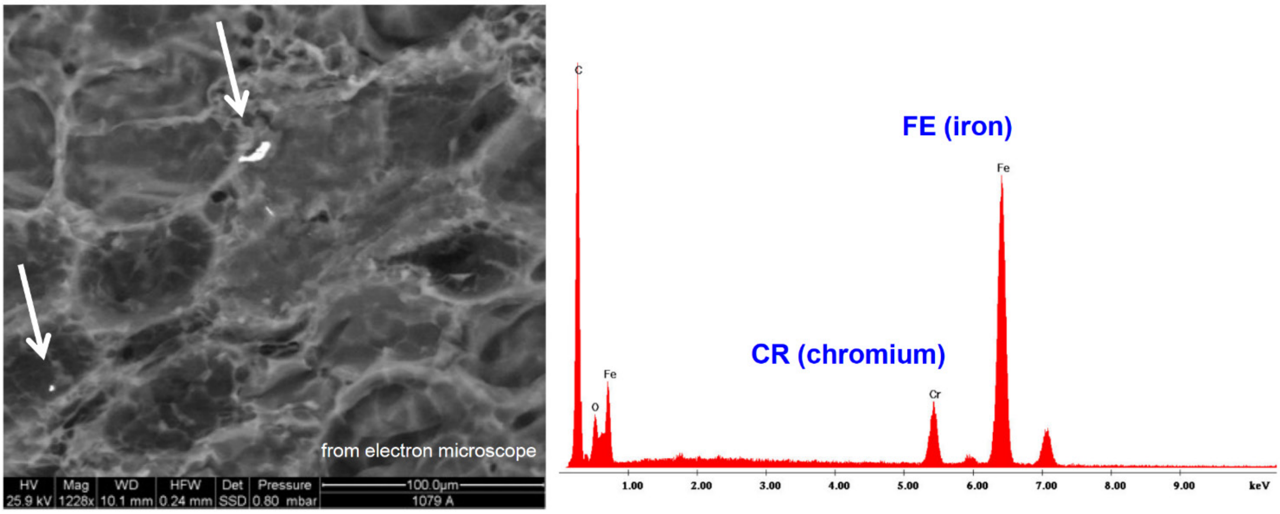

Figure 4 Analysis 8 of Table I. High-magnification image (1228x) and EDS (Energy-Dispersive X-ray spectroscopy) spectrum of 10-micron and 1-micron brighter-looking particles composed of Carbon, Iron, Chromium and Oxygen: a stainless-steel composition (Gatti 2019, report written for client).

3 Distribution of Engine Oil with Metal Nanoparticles

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. **Figure 5** shows the route of the engine oil into the cabin.

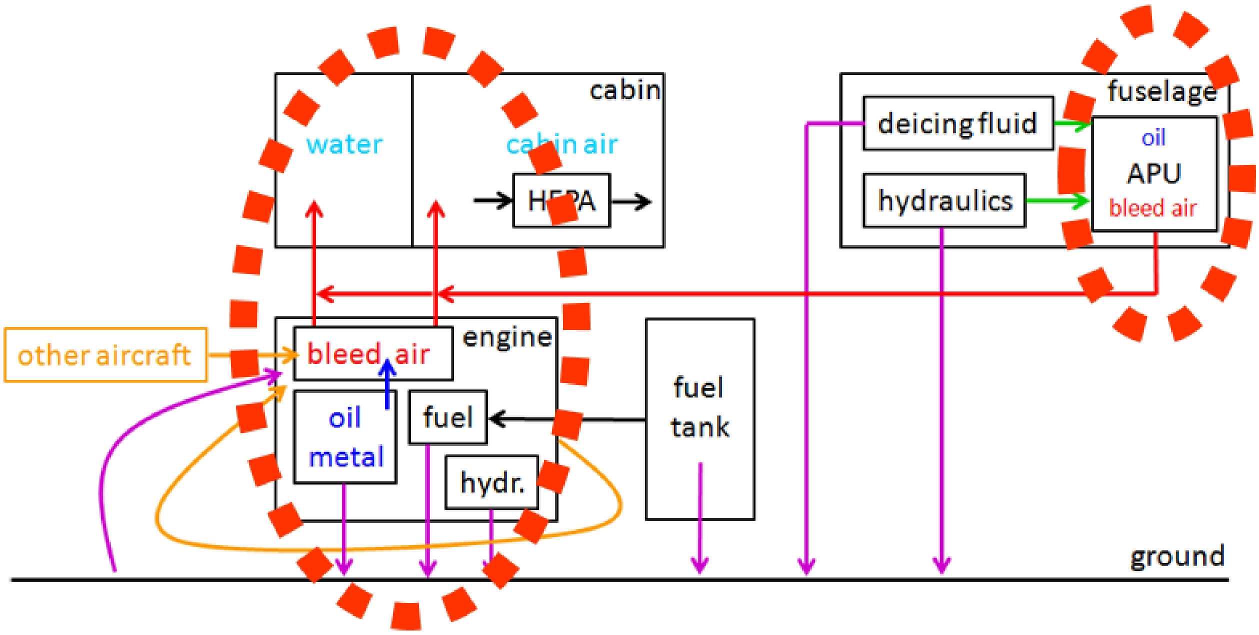

Figure 5 The route of engine oil into the cabin.

The **Figures 6 to 9** show the inside of a cabin in a Cabin Air Contamination Event (CACE) due to engine oil after a technical fault.

Figure 6 2010-09-17, US Airways US-432, Boeing 757-200. Maui-bound flight enroute overhead the Pacific diverted to San Francisco (1200 nm). More: AvHerald 2010. Picture source: Video: https://youtu.be/AZqeA32Em2s.

Figure 7 2018-12-10, Indigo flight 6E-237, Airbus A320neo, Jaipur to Kolkata, India. The smoke was traced down to the engines (PW1127). This and more: AvHerald 2018. Cause: Leakage of oil from the engine (Telegraph 2018). Picture source: Video: https://youtu.be/TO_FZ3L4yus.

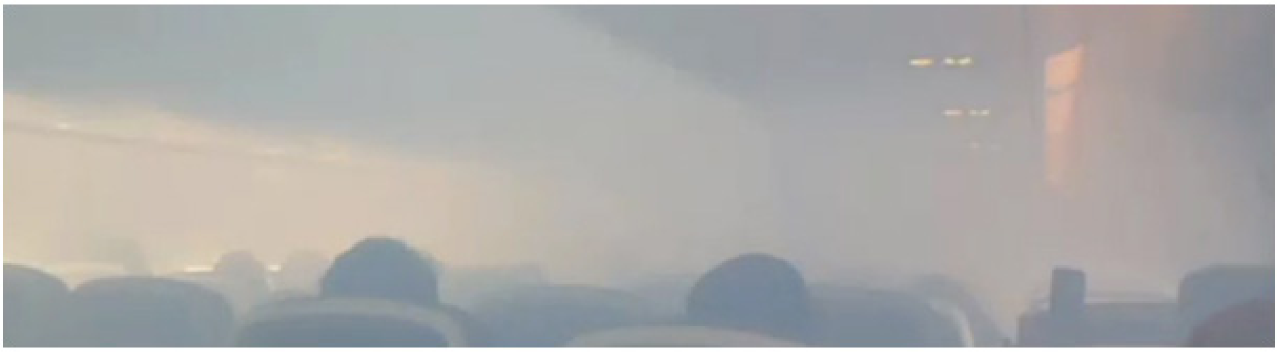

Figure 8 2019-08-22, Hawaiian Airlines HA47, A321neo. Emergency landing and evacuation after smoke on board. Cause: Seal failure in left engine. Picture source: Glen Westenskow. This picture and more: AvHerald 2019a. More also on https://purl.org/cabinair/HA47.

Figure 9 2019-08-05, British Airways BA-422, Airbus A321. On a flight from London Heathrow to Valencia, the aircraft was descending towards Valencia when smoke appeared in the cabin. It followed an emergency evacuation. The aircraft remained 9 days in Valencia and was subsequently ferried to London. After a total of 31 days the aircraft returned back to service (Ayan 2020). "It was found that no fire had occurred, but engine #2 (V2533, right hand) had lost all its oil. The engine was removed from the airframe and sent to the manufacturer for thorough inspection." This and more on: AvHerald 2019b. Picture source: Lucy Brown. Video: https://youtu.be/tFsN0h09gAI.

3.1 Engine Oil in the Potable Water

Compressed air from the engine is also used to pressurize the potable water tanks on some aircraft like the Airbus A320 (Scholz 2014b). It has been observed that the potable water on board can also be contaminated. Potable water contaminated by bleed air on an Airbus A320, is shown in **Figure 10**. It is the last water extracted from the tank before it is empty. This water is black, probably from engine oil residue.

Figure 10
Potable water contaminated by bleed air on an Airbus A320. This is the last water extracted from the tank before it is empty. This water is black, probably from engine oil residue. Picture source is a Video: https://youtu.be/dlPOeudTTCI. The video is explained: On the A320 the potable water tank is pressurized with bleed air. On the A320 also the hydraulic reservoirs are pressurized with bleed air. The bleed air presses on the free surface of the hydraulic fluid and gets as such in contact with it. The "mixture of hydraulic fluid vapor and bleed air" is connected via bleed lines with the potable water tanks. But flow into the potable water tanks is unlikely:

- In flight, the "mixture of hydraulic fluid vapor and bleed air" would need to flow upstream and opposite sense through two check valves (which by design will not happen in larger quantity) to get into the bleed line for water pressurization.
- On the ground (without bleed pressure), the hydraulic fluid vapor and bleed air mixture can flow downstream(!) but would still need to flow opposite sense through two check valves (which by design will not happen in larger quantity) to get into the bleed line for water pressurization.

3.2 Engine Oil Colors Bleed Air Ducts

When an engine is taken off the aircraft, two air ducts become visible: the duct for the fan air and the duct for the bleed air. Fan air and bleed air ducts at the interface between engine and wing carry outside compressed air. **Figure 11** shows a diagram from the Airbus A320. The red line indicates the cut when separating the engine from the wing. The fan air is fresh outside air that has at best touched the fan blades (or the outlet guide vanes) on its way through the engine bypass. On the other hand, the bleed air is fresh outside air that has gone through the core of the engine. If everything were right, there should not be a difference depending on where the outside air gets compressed. Unfortunately, there is a difference. Bleed air is potentially contaminated with engine oil. This can be seen in **Figure 12**. The fan air duct shows a normal metallic surface color, whereas the bleed air duct at the engine interface appears brown. The bleed air temperature at this point is about 300 °C ... 400 °C, the fan air is closer to ambient temperature. Metal on its own does not turn to a brown color when heated to 400 °C. The only explanation with respect to the difference in the color of the two ducts is that the bleed air is covered by a brown residue. Confirmation comes from touching the surface. If not deposited in the duct, the substance causing the residue makes otherwise its way into the cabin. We know from engineering (**Figure 3**) that jet engine seals leak oil by design. Therefore, the brown residue in the bleed air duct compared to the fan air duct is a confirmation that oil leakage takes place in the engine.

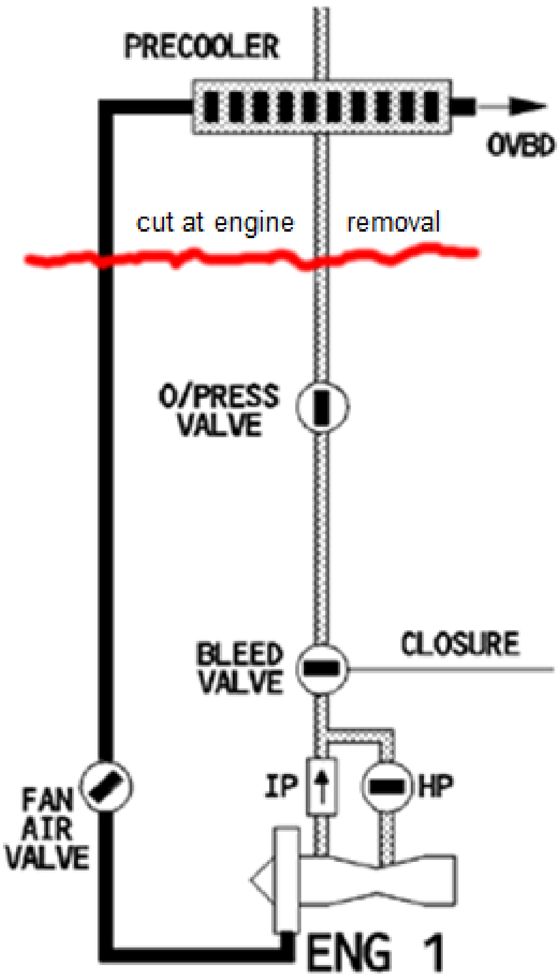

Figure 11 Fan air and bleed air taken off a jet engine. The red line indicates where the fan air duct and the bleed air duct are separated, when the engine is taken off. The diagram is a simplification based on a diagram explaining the pneumatic system (ATA 36) in the Airbus A320 FCOM.

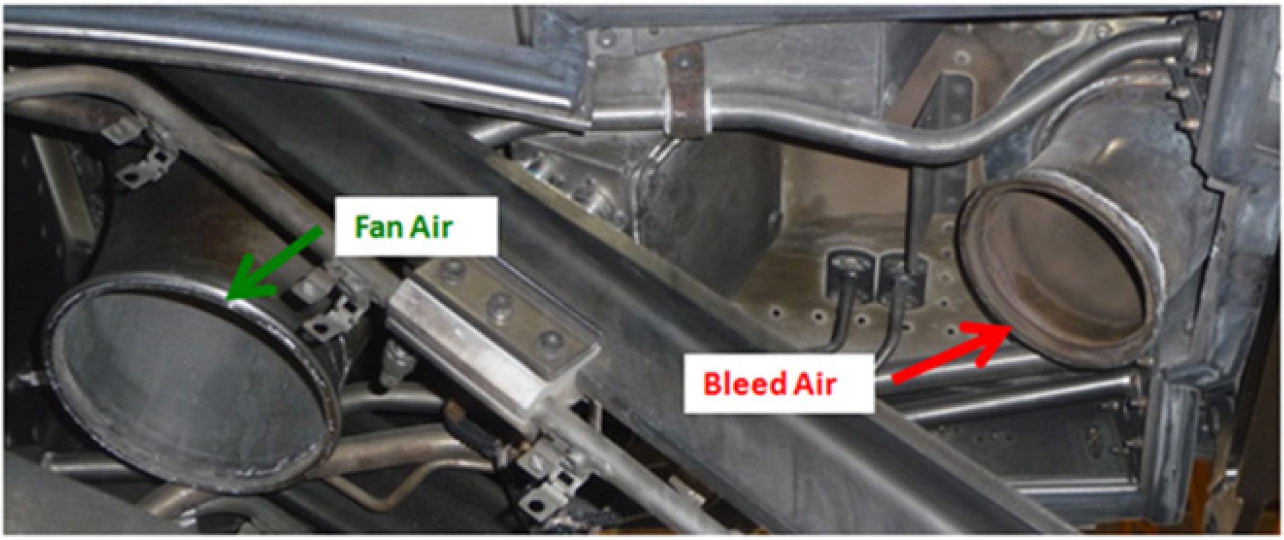

Figure 12 Bleed air duct with brown stain compared to a clean fain air duct on an Airbus A320.

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. **Figure 13** shows bleed air duct of a Boeing 737 with black oil residue inside.

Figure 13 Engine oil colors bleed air duct black. Picture source: Video: https://vimeo.com/groups/617439/videos/345959025.

The water extractor is a part of the air conditioning pack. **Figure 14** shows the Airbus A320 water extractor. The inlet of the water extractor is covered with black oily residue because the temperature is even lower at this point.

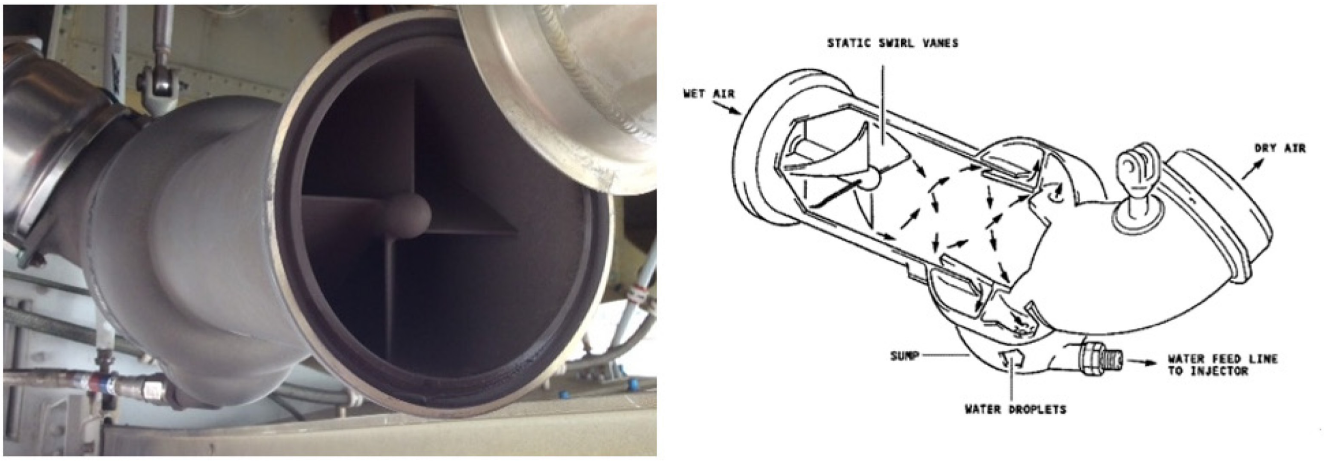

Figure 14 Engine oil residue accumulates in water extractor. The schematic on the right is from Airbus 1999.

3.3 Engine Oil Colors Cabin Air Ducts

The air conditioning air distribution ducts in the cabin are black inside from contaminated bleed air. **Figure 15** shows the Airbus A320 air conditioning air distribution duct in the cabin. The inside is black from contaminated bleed air.

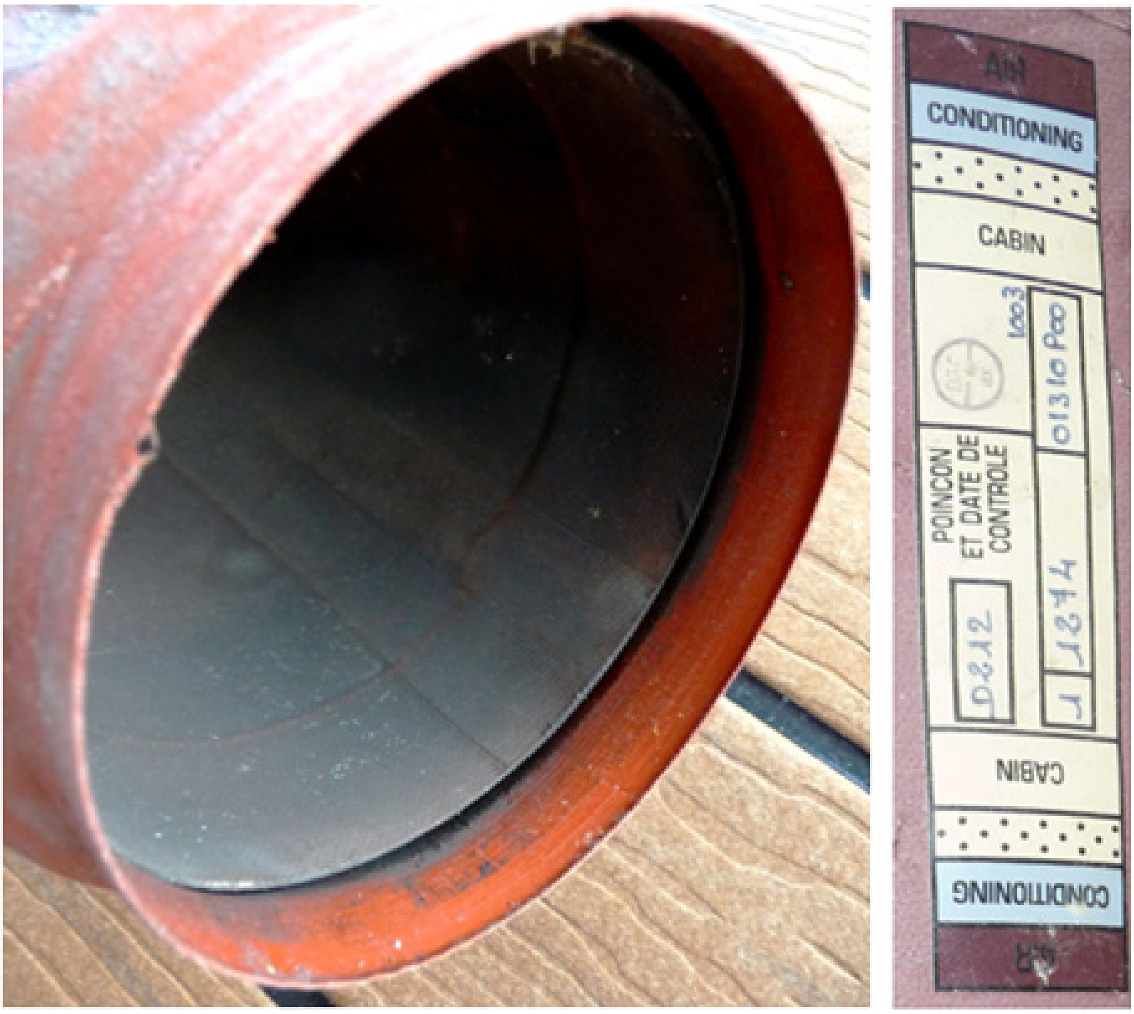

Figure 15 Airbus A320 air conditioning air distribution duct in the cabin.

Figure 16 shows on the left side an unused duct supplied new. The right side of Figure 16 shows the same duct that had been installed downstream of the environmental control system air conditioning packs on a BAe 146 passenger aircraft after 26061 flight hours.

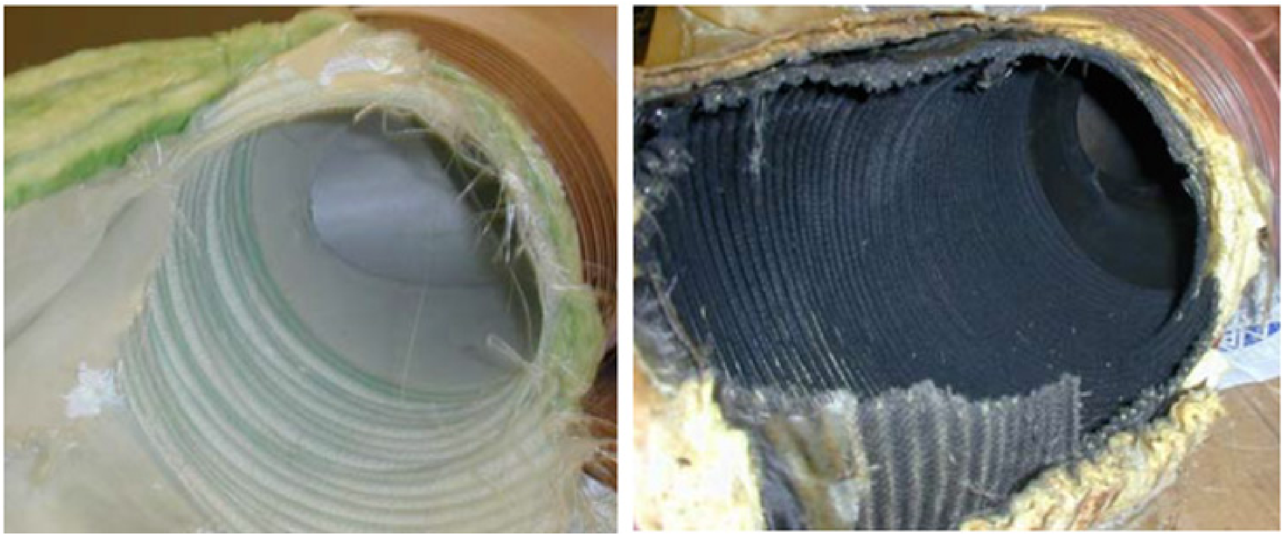

Figure 16 Left: Unused cabin air duct. Right: Used cabin air duct on a BAe 146 passenger aircraft (CAA 2004).

Air ducts 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. Such an example is shown in **Figure 17**. 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. This disproves the argument that all ducts are black due to normal use over the course of decades in service.

Figure 17 Clean air duct at end of life of an Airbus A320.

Flow limiter in air conditioning ducts have been found in ducts of the air conditioning system that are clogged from engine oil. **Figure 18** shows flow limiters clogged from pyrolyzed 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, left).

Figure 18 Top left: Clean flow limiter in an air conditioning duct on an Airbus A320 (here in a dead-end duct section) compared to flow limiters clogged from pyrolyzed engine oil in ducts of the air conditioning system of Boeing 757 aircraft (Hansen 2019).

Figure 19 shows the riser ducts and lower cabin air outlet on an Airbus A320 aircraft. The red line in Figure 19 close to the cabin floor indicates where the duct was separated and opened. Looking down to the cabin floor shows a duct feeding the riser ducts. It is black inside from engine oil residue. **Figure 20** shows a view into the riser duct at that end, where it was separated at the cabin floor. It is also black inside.

It has been argued that on old aircraft, cabin air ducts could be black inside due to cigarette smoke. This however is not likely for three reasons:

1. The bans on inflight smoking have been introduced gradually around the world beginning in the 1980s. An aircraft that flying or is parted out today (like the one from which most of the picture are taken) will most probably have not seen any onboard smoking.
2. Air can only get into the cabin air ducts after it has be recirculated through the HEPA filters, which would filter out smoke particles.
3. Ducts are contaminated starting from the bleed air ducts connected with the engine. Cigarette smoke would not explain contamination of these ducts.

Figure 19 Left: Riser ducts and lower cabin air outlet on an Airbus A320 aircraft. The red line close to the cabin floor shows, where the riser ducts are attached to their supply duct. See: Video: https://bit.ly/2YXcL3a (English subtitles available).

Top: View into the supply duct leading up into the riser duct on an Airbus A320. The inside is covered by a black residue.

Figure 20 View into the riser duct where it was separated at the cabin floor. It is covered inside by black residue.

3.4 Engine Oil on Overhead Bins

Cleaning on top of the overhead bins of an Airbus A320 brings to light dirt that is clearly more than dust. The black residue similar to that known from the ducts settles also on the bin surface, as shown on the left side of **Figure 21**. The right side of **Figure 21** shows an Airbus A320 cabin cross section with the upper cabin air outlet releasing potentially contaminated air on top of the overhead bins.

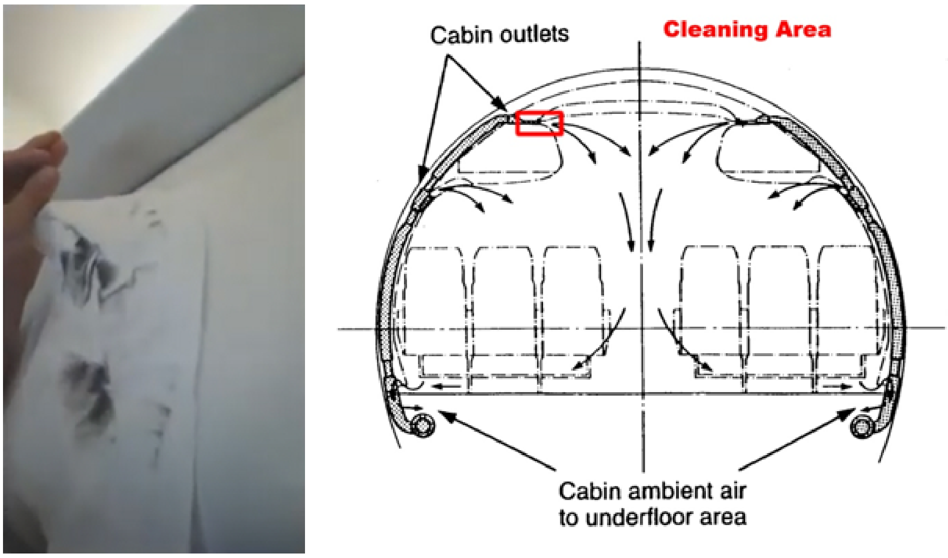

Figure 21 Left: Cleaning on top of the overhead bins of an Airbus A320 brings to light dirt that is clearly more than dust. The black residue known from the ducts settles also on the bin surface. Picture source: Video: https://youtu.be/uQfA_DiMBS8. Right: Airbus A320 cabin cross section with the upper cabin air outlet releasing potentially contaminated air on top of the overhead bins (based on Airbus 1999).

4 Distribution of Hydraulic and Deicing Fluid

Figure 22 shows the route of hydraulic and deicing fluid into the cabin.

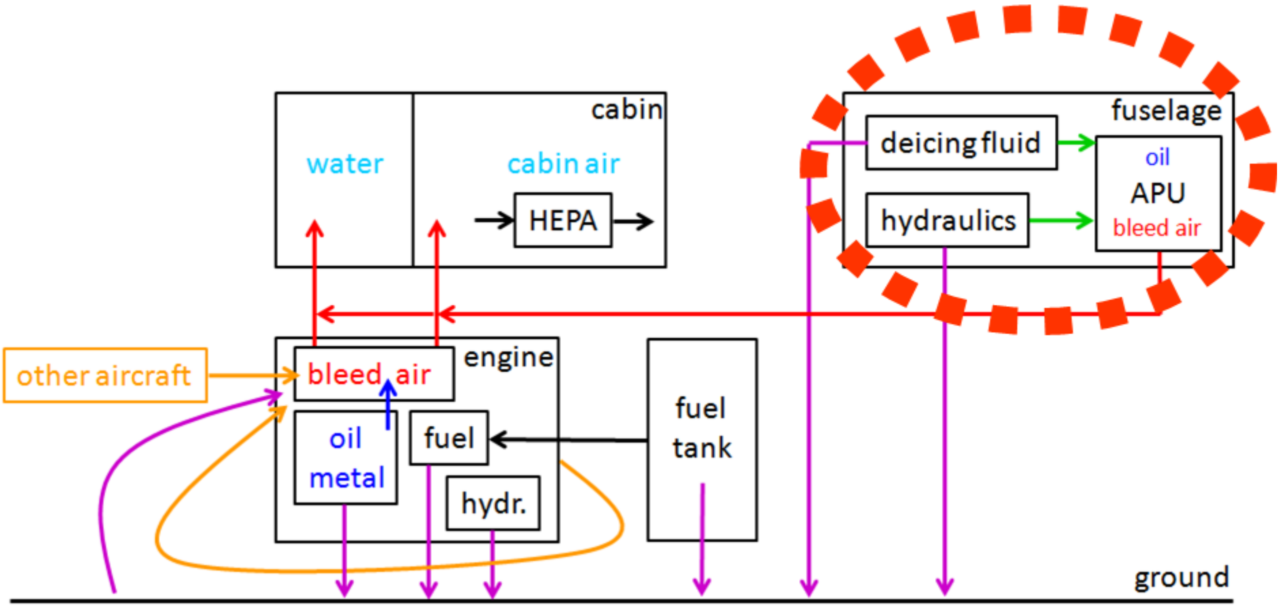

Figure 22 The route of hydraulic and deicing fluid into the cabin.

4.1 APU Air Intake

Deicing fluid and hydraulic fluid can find their way into the air conditioning system via the APU air intake. The location of the APU air intake is shown in **Figure 23**.

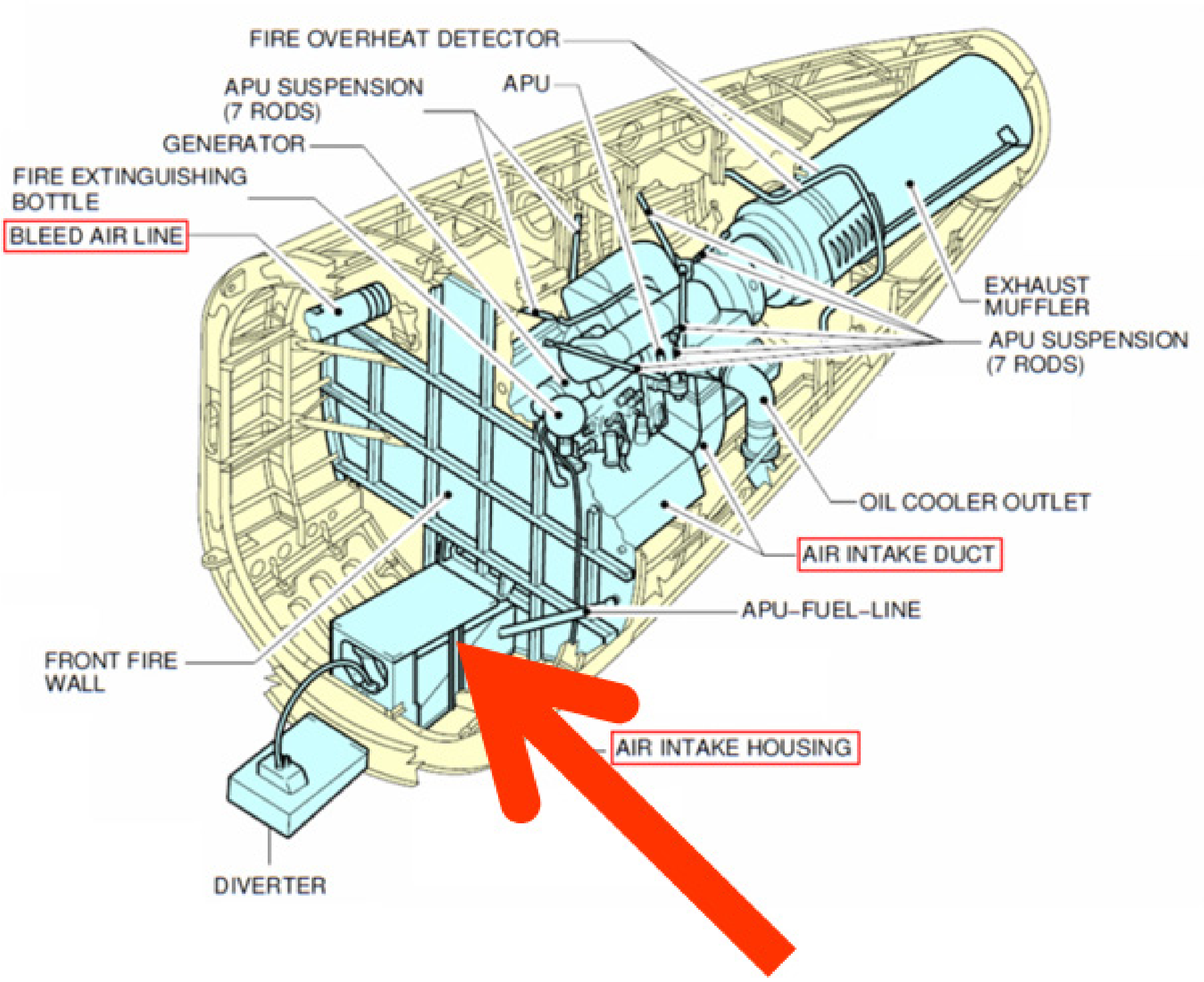

Figure 23 APU air intake (Airbus 2020).

The left side of the **Figure 24** shows the 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. On the right side of Figure 24 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.

Figure 24 Air intake of the A320 APU. Source of picture on the right: Airbus 2019.

4.2 No "Zero Leakage" of Hydraulic Systems

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. **Figure 25 and 26** show the forward and aft collector tank of the A320 hydraulic seal drain system.

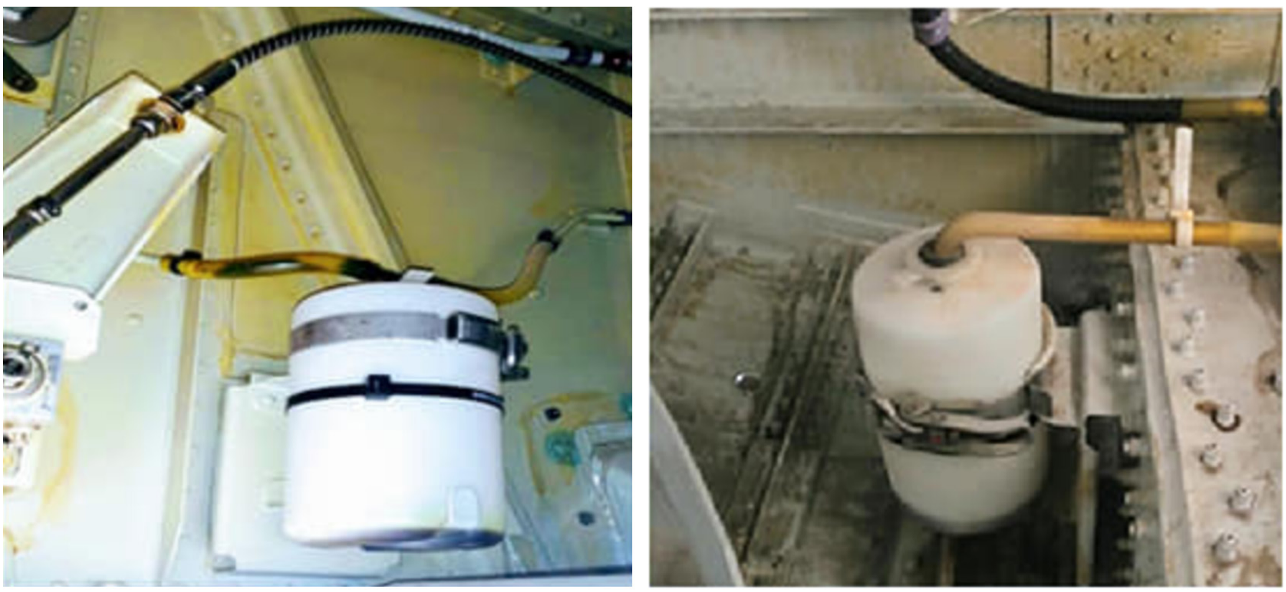

Figure 25 Forward (left) and aft (right) collector tank of the A320 seal drain system (Mekanikong 2019a and 2019b).

Figure 26
Aft collector tank of the A320 seal drain system, ATA 29-17 (Mekanikong 2019b). Forward and aft collector tanks collect hydraulic fluid from leaking equipment in the landing gear compartment, but spillover into the landing gear compartment when full. The photo tries to explain, what is meant with "the hydraulics industry must clean up its messy image". 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. Logically, the hydraulic fluid is not confined to the inside of the hydraulic bay, but continues the lower side of the fuselage, if not cleaned constantly.

4.3 Aircraft Deicing

In **Figure 27** shows how deicing fluid is applied and how it covers the surface of an aircraft. The purpose is to clean the aircraft from frost and snow and to protect it from further onset. Deicing fluid can leak from the tail into the APU inlet as shown in **Figure 28**.

Figure 27 Leakage of deicing fluid (Petchenik 2015).

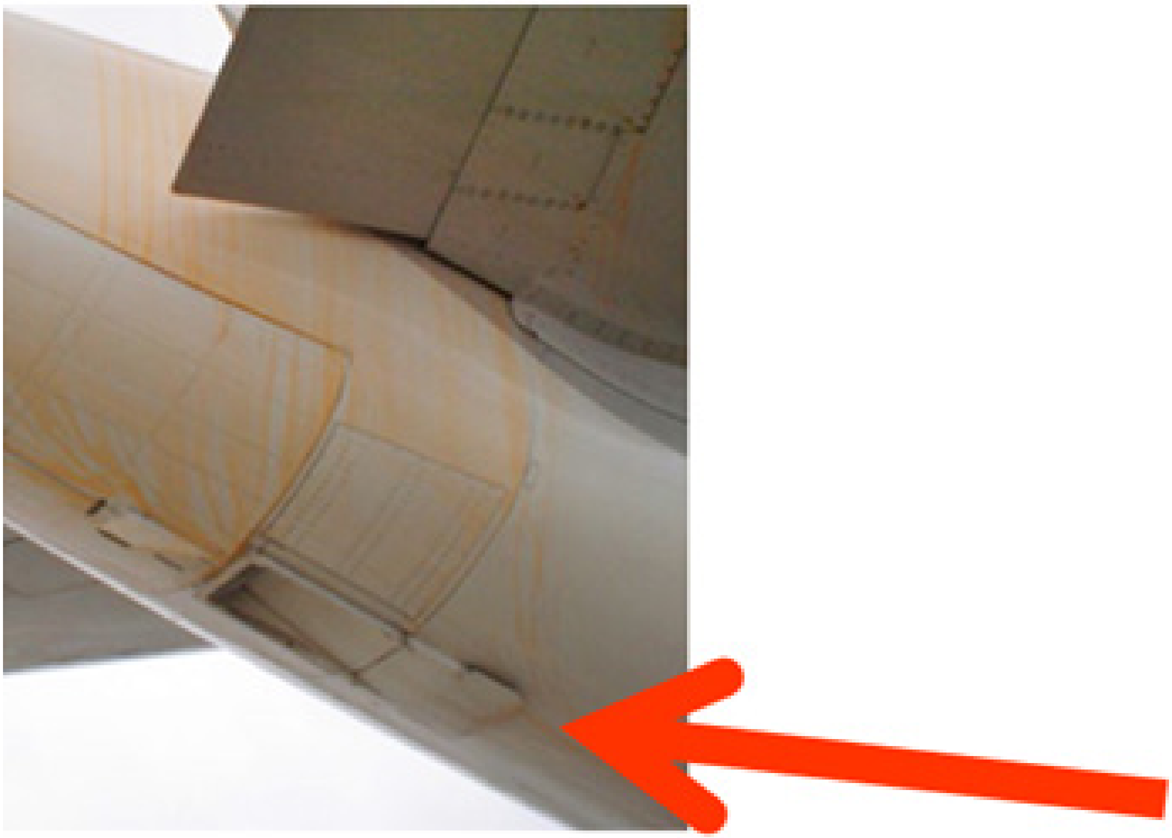

Figure 28 Leakage of deicing fluid on the lower side of the fuselage (Vera-Barcelo 2013).

5 Distribution of Fluids via the Airport Surface

Fuel and oil also leak down onto the airport surfaces. Figure 29 shows the route of fluids down to the ground and back into the engine.

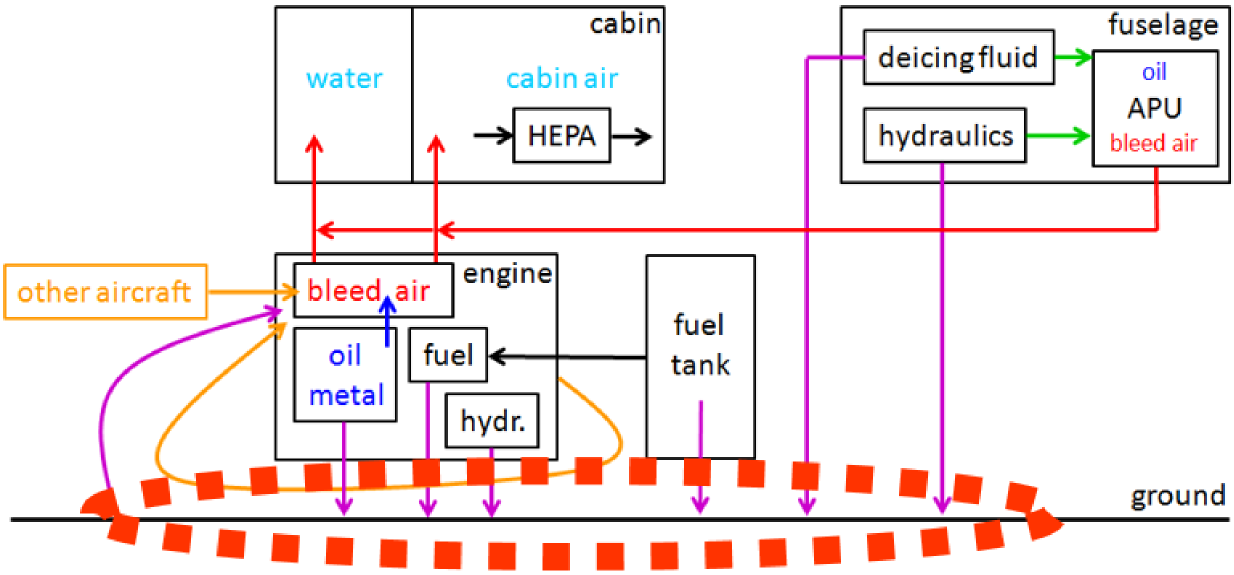

Figure 29 The route of fluids down to the ground and back into the engine.

5.1 Leak Limits of Aircraft Equipment

There are leak limits of aircraft equipment as shown in **Figure 30**. These leak limits show that it is normal for fluids to drip in smaller quantities on the ground. However, an airport sees many airplanes dripping and it all adds up over weeks, months and years.

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)

Figure 30 A320 leak limits for the CFM56-5B engine in drops per minute. Drops add up over time (Mekanikong 2019c). AGB: Accessory Gearbox.

5.2 Intake of Fluids by the Engine

Fluids that leak on the ground can be ingested by the engine from the ground and can enter the air conditioning system from there. **Figure 31** shows the simulation of two intake vortices, one of them as ground vortex. The rotation of the vortex is visible. **Figure 32** shows the same situation in a photograph.

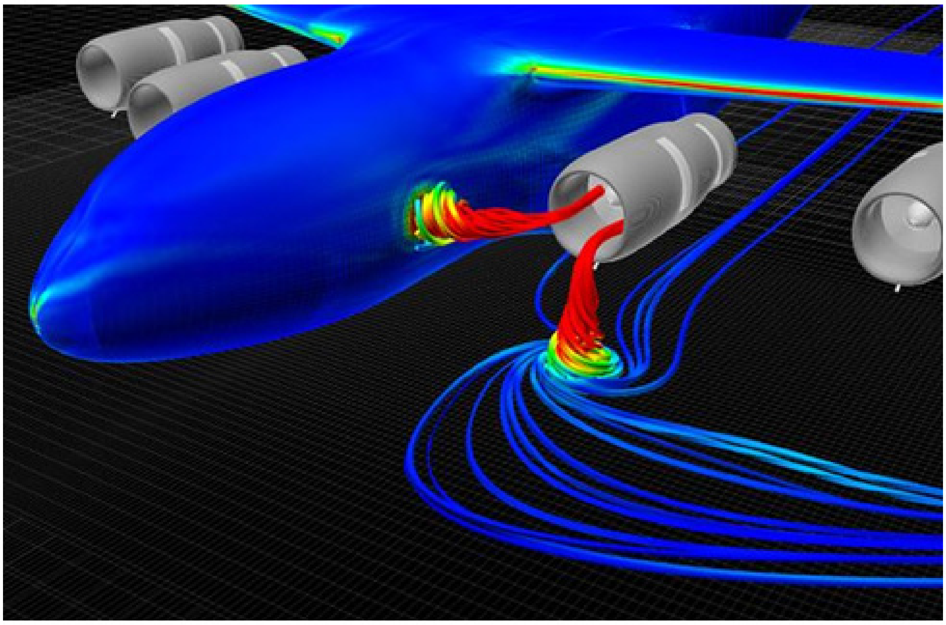

Figure 31 Simulation of two intake vortices, one of them as a ground vortex. The rotation of the vortex is visible. Picture source: https://perma.cc/VH99-87XS.

Figure 32 The ground vortex can also form between the ground and an engine on a high wing (Childs 2017).

6 More Contamination

The location of the recirculation fan of an Airbus A320 is shown in **Figure 33**. The face of the recirculation fan of an Airbus A320 is covered by an oily black soft substance that can be scraped off with a screwdriver (**Figure 34**).

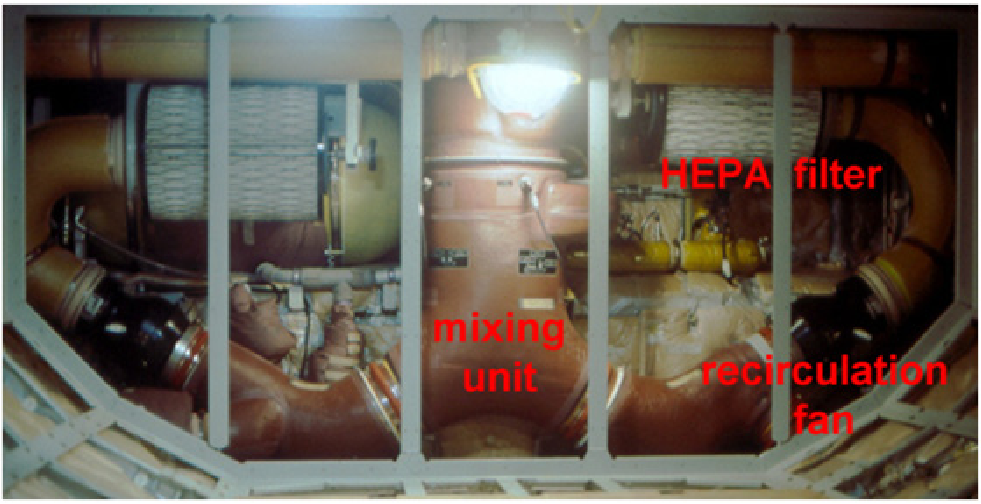

Figure 33 The main component of the Airbus A320 recirculation system. View from the forward cargo compartment looking aft. The wall panels in the cargo compartment are not installed. The support frames for the wall panels are visible. Two HEPA filters and two recirculation fans are installed symmetrically.

Figure 34 The recirculation fan of an Airbus A320 is covered by an oily black soft substance that can be scraped off with a screw driver. Picture source: Video: https://bit.ly/2YXcL3a (English subtitles available). A disassembled recirculation fan is shown on the right.

Figure 35 shows 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.

Figure 35 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.

7 Conclusions

Entropy is the law of nature that states that disorder always increases, as shown in **Figure 36**. 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.

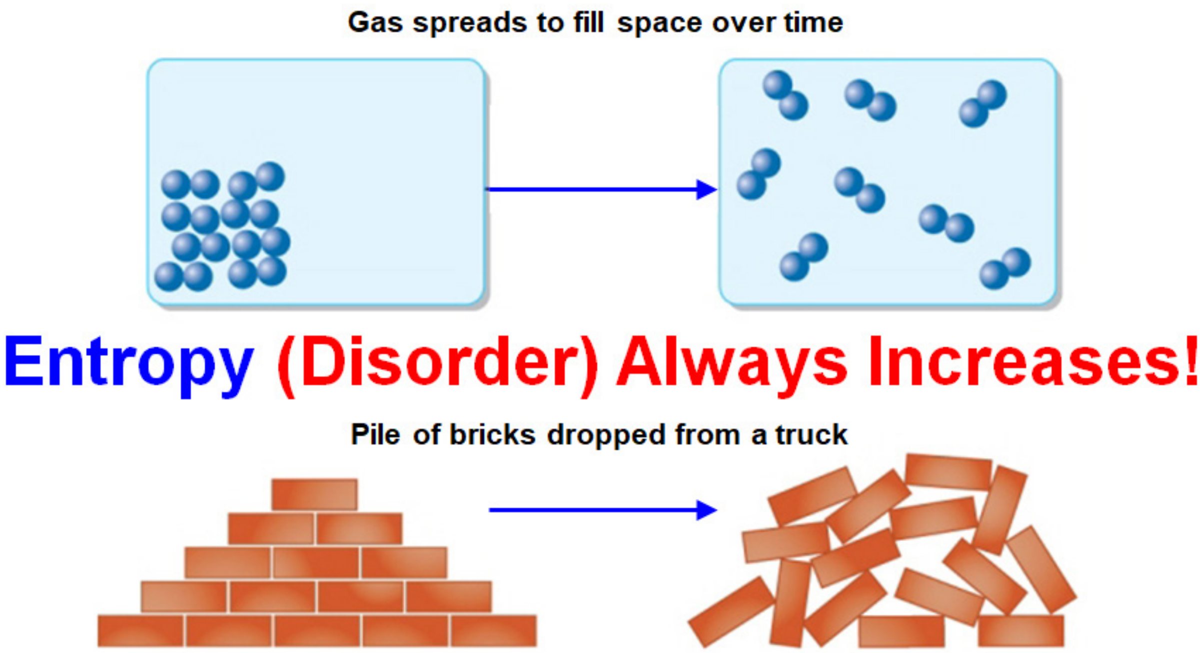

Figure 36 Disorder always increases (based on https://perma.cc/A6KL-XS9R).

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