Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

AIRCRAFT DESIGN AND SYSTEMS GROUP (AERO)

Fire Protection in Aviation

Dieter Scholz Hamburg University of Applied Sciences

https://doi.org/10.48441/4427.2348

Tagung und Fortbildung Brandschutz

Rilano, Hamburg-Finkenwerder, 06./07. März 2025

Abstract

Fatalities on passenger aircraft have several reasons and occur with different numbers. Fire and smoke on board is not the worst in this comparison, but it deserves attention. Aircraft are designed with multiple redundancies, but undetected manufacturing defects or inadequate maintenance can still be catastrophic. Sorting with respect to flight phase, we have in-flight fires that need to be taken care of by an aircraft system itself. The system is called "Fire Protection" (ATA 26). A fire on the aircraft while it is on the ramp as well as a post-crash fire is taken care of by Aircraft Rescue and Firefighting (ARFF) located at the airport. In-flight fires can be hidden fires (electric circuit), visible fires in the cabin, or from the engine or Auxiliary Power Unit (APU) – a gas turbine in the tail of the aircraft that provides electric power and compressed air. Protection against fire and smoke on board is by prevention, slow growth policy (flame-retardants), detection, and extinguishing. Certification rules on fire protection are in place that regulate the design of the aircraft. Rules are from certification authorities (EASA, FAA, ...) and in addition from aircraft manufacturers (Airbus with its ABD0031). Certification rules on fire protection are revisited regularly and have been written more stringent, but ways to improve safety still exist. As often, a compromise between safety and economics must be found. EASA CS-25.803 "Emergency Evacuation" demands that an aircraft can be evacuated under simulated emergency conditions (doors on one side are closed, ...) within 90 seconds. This is a good but arbitrary standard. Its validity can be challenged, when looking at evacuation with fire and smoke and with other combinations of doors in use. Many emergency landings took place with smoke on board, where it turned out later that the smoke was not from a fire, but from engine oil transported into the cabin and cockpit by means of so-called bleed air from the engines. The problem is a fundamentally wrong design principle applied for the environmental control system (ECS) of all present passenger aircraft (except for the Boeing 787). It is wrong to use (unfiltered) compressed air from the engine (bleed air). Instead outside air must be compressed in dedicated compressors using air from a separate inlet. Smoke and fumes from the engine (or APU) does not require to land As Soon As Possible (LASAP) as in case of a fire. Nevertheless, pyrolyzed engine oil (and hydraulic fluid) is toxic and has caused crew and passengers to get acutely and chronically ill.

Contents

Fatalities on Passenger Aircraft

Fatalities on Passenger Aircraft

1. Terrorism/Hijacking

- **Why it ranks high**: A few large-scale acts—particularly the events of September 11, 2001—caused extremely high casualties in a single day, overshadowing most other individual accidents.
- **Key points**: Though rare, deliberate sabotage or hijacking can result in catastrophic loss of life.

2. Pilot Error and Loss of Control

- **Why it ranks high**: Over the decades, human factors—including misjudgments, fatigue, poor decision-making, and inadequate response to emergencies—have been among the most persistent causes of accidents.
- **Key points**: Ongoing improvements in training and cockpit automation help reduce such errors, but human oversight remains critical.

3. Controlled Flight Into Terrain (CFIT)

- **Why it ranks high**: CFIT accidents occur when a fully functional aircraft is unintentionally flown into the ground, water, or obstacles.
- **Key points**: Often stems from navigation errors, poor visibility, or breakdowns in pilot–controller communication.

4. Mechanical or Structural Failures

- **Why it ranks high**: Failures in critical systems—engines, hydraulics, airframes—have led to major accidents over the history of aviation.
- **Key points**: Aircraft are designed with multiple redundancies, but undetected manufacturing defects or inadequate maintenance can still be catastrophic.

5. Adverse Weather Conditions

- **Why it ranks high**: Weather-related accidents can involve wind shear, icing, heavy storms, or turbulence.
- **Key points**: Modern forecasting and onboard weather radar have reduced these risks, but sudden phenomena (e.g., microbursts) still pose hazards.

Fatalities on Passenger Aircraft

6. Fire/Smoke Onboard (In-Flight, On the Ramp, or Post-Crash)

- **Why it matters**: In-flight fires or smoke can rapidly disable critical systems, fill the cabin with toxic fumes, or incapacitate the crew. Even if an aircraft lands safely, smoke and flames can hamper evacuation.
- **Examples:**
  - In-flight electrical fires (e.g., Swissair Flight 111)
  - Cargo fires (e.g., ValuJet Flight 592)
  - Post-crash fires that spread quickly, making escape more difficult (e.g., Saudia Flight 163)

7. Runway Incidents (Excursions/Collisions)

- **Why it ranks here**: Takeoffs and landings are high-risk phases of flight; runway overruns, undershoots, and collisions have led to numerous fatalities.
- **Key points**: The deadliest accident in aviation history (Tenerife, 1977) was a runway collision. Improved runway safety areas, better airport lighting, and advanced alerting systems aim to reduce these incidents.

Key points:

- **Aircraft are designed with multiple redundancies**, but undetected manufacturing defects or inadequate maintenance can still be catastrophic.
- **Fire/Smoke does not cause highest number of fatalities**, nevertheless it is important enough to get into the topic

Fatalities on Passenger Aircraft

Important Notes

- **Overlap of causes**: Many fatal accidents stem from a chain of errors or failures rather than a single cause. For example, a mechanical issue might lead to an in-flight fire, which in turn overwhelms the crew and results in a crash.
- **Statistical variability**: The relative ranking can change based on time and location and whether you classify terrorism and sabotage separately from “typical” operational causes.
- **Continuous improvements**: Aviation safety has significantly advanced in all these areas, making accidents increasingly rare despite growing air traffic.

Aircraft Fire & Smoke: Background

Aircraft Fire & Smoke: Background

Flight Phase, Type, Protection

- Flight phase:
  - ramp fire => Aircraft Rescue and Firefighting (ARFF)
  - in-flight fire => Aircraft System: Fire Protection (ATA 26)
  - post-crash fire => Aircraft Rescue and Firefighting (ARFF)
- Type of fire (in-flight):
  - engine fire or APU fire => remote extinguishing
  - hidden fire (e.g. electric circuit) => circuit deactivation
  - cabin fire => handled by cabin crew (fire extinguisher, smoke hood)
- Protection against fire and smoke on board:
  - prevention
  - slow growth: flame-retardants (FR)
  - detection
  - extinguishing

Aircraft Fire & Smoke: Background

Reasons for Fire & Smoke

- Electrical System Failures
  Faulty Wiring or Components. Malfunctioning Devices.
- Galley Equipment Malfunctions
  Overheated Appliances. Spilled Fluids.
- Lithium-Ion Battery Incidents
  Thermal Runaway. Faulty Battery Management.
- Smoking Materials or Misuse of Electronic Cigarettes
  Unauthorized Smoking. Improper Disposal.
- Storage of Flammable Materials
  Improperly Secured Items. Chemical Exposure.
- Maintenance or Design Issues
  Component Degradation. Systemic Design Vulnerabilities.

Safety Measures

Airlines and regulatory bodies (like the FAA and EASA) rigorously enforce maintenance protocols, perform regular inspections, and equip aircraft with early detection and suppression systems to minimize these risks. Crew training also plays a crucial role in managing such events should they occur. Each of these factors is taken very seriously in the design and operation of modern aircraft to ensure passenger safety.

Chemicals / Flame-Retardants

Chemicals / Flame-Retardants

Off-gassing from Cabin Material / Delay in Fire and Smoke Generation

Plastics cabin material can produce Volatile Organic Compounds (VOC). VOC are set free from **plastic cabin material** due to **off-gassing** of plasticizers and solvents. Furthermore, **fibrous cabin material** contains flame-retardants (FRs) that can be **present in dust** in the cabin air or in dust settled in the carpet or in seat pockets. Dust is Particulate Matter (PM). VOC and PM can reach and interfere with the human body.

Here are the details about **flame-retardants** (FRs) used in fibrous cabin material (Uddin 2016). A cabin fire can be detected by passengers and the crew. It can be contained by the crew using hand fire extinguishers. **FR fibrous materials resist the initiation of fire and can cause a delay in the fire and smoke generation.** In an airborne fire, this delay may be decisive for a successful aircraft descent, landing, and cabin evacuation.

UDDIN, Faheem, 2016. Flame-Retardant Fibrous Materials in an Aircraft. In: *Journal of Industrial Textiles*, vol. 45, no. 5, pp. 1128-1169.
Available from: https:/doi.org/10.1177/1528083714540700
Archived at: https://perma.cc/Q7T8-UAD9

Fibrous materials used in aircraft production are:

- acoustic and thermal insulation,
- ducting, electric wire insulation,
- emergency slides,
- floor panels, floor covering (carpeting),
- side walls, partitions, ceiling, passenger service units,
- seat cushions and upholstery.

These are the components with the largest mass fractions. More components exist. In total, a passenger aircraft can have between 3 tons and 9 tons of such combustible materials plus carry-on baggage. The combustion of this would produce an enormous amount of heat. Desired properties of fibrous materials are flame retardancy, high strength, low mass, thermal stability, chemical and corrosion resistance.

Classically, halogenated flame-retardants were in use, specifically brominated FRs (BFRs) as polybrominated diphenyl ethers (PBDEs) with three commercial products: pentaBDE, octaBDE, and decaBDE. Halogenated FRs reduce the flammability of burning material by decomposing and producing non-flammable gases. All commercially relevant PBDEs have been marked for elimination under the Stockholm Convention for their toxicity and persistence in nature.

The ingestion of dust accounts for most of human exposure. Due to the long life of passenger aircraft, PBDEs will be around in older aircraft for decades to come. Natural FR fibers exist. Wool and cotton need to be blended with other materials to reach required properties. The cotton/nylon blend is one example. Novel brominated FRs (NBFRs) are a substitute. FR chemicals are not named in the certification rules, but the rules demand stringent fire test procedure that cannot be met unless FRs are applied. These are the paragraphs: EASA CS-25, Subpart D – Design and Construction, Fire Protection, CS-25.851 to CS 25.869 and Appendices to CS-25, Appendix F, Part I – Test Criteria and Procedures.

Certification Rules

HAW HAMBURG

EASA
European Union Aviation Safety Agency

Certification Specifications and Acceptable Means of Compliance for Large Aeroplanes (CS-25)

https://www.easa.europa.eu/en/document-library/certification-specifications/cs-25-amendment-27

FIRE PROTECTION

- CS 25.851 Fire extinguishers
- CS 25.853 Compartment interiors
- CS 25.854 Lavatory fire protection
- CS 25.855 Cargo or baggage compartments
- CS 25.856 Thermal/acoustic insulation materials
- CS 25.857 Cargo compartment classification
- CS 25.858 Cargo or baggage compartment smoke or fire detection systems
- CS 25.859 Combustion heater fire protection
- CS 25.863 Flammable fluid fire protection
- CS 25.865 Fire protection of flight controls, engine mounts, and other flight structure
- CS 25.867 Fire protection: other components
- CS 25.869 Fire protection: systems

SUBPART D – DESIGN AND CONSTRUCTION

FIRE PROTECTION

CS 25.851 Fire extinguishers

ED Decision 2016/010/R

(See AMC 25.851)

(a) *Hand fire extinguishers*. (See AMC 25.851(a).)

(1) The following minimum number of hand fire extinguishers must be conveniently located and evenly distributed in passenger compartments. (See AMC 25.851(a)(1).):

Passenger capacity	Number of extinguishers
7 to 30	1
31 to 60	2
61 to 200	3
201 to 300	4
301 to 400	5

https://www.easa.europa.eu/en/document-library/easy-access-rules/online-publications/easy-access-rules-large-aeroplanes-cs-25

CS 25.853 Compartment interiors

ED Decision 2019/013/R

(See AMC 25.853)

For each compartment occupied by the crew or passengers, the following apply:

(a) Materials (including finishes or decorative surfaces applied to the materials) must meet the applicable test criteria prescribed in Part I of Appendix F or other approved equivalent methods, regardless of the passenger capacity of the aeroplane.

(b) *Reserved*

(c) In addition to meeting the requirements of sub-paragraph (a) of this paragraph, seat cushions, except those on flight crewmember seats, must meet the test requirements of part II of appendix F, or other equivalent methods, regardless of the passenger capacity of the aeroplane.

(d) Except as provided in sub-paragraph (e) of this paragraph, the following interior components of aeroplanes with passenger capacities of 20 or more must also meet the test requirements of parts IV and V of appendix F, or other approved equivalent method, in addition to the flammability requirements prescribed in sub-paragraph (a) of this paragraph:

(1) Interior ceiling and wall panels, other than lighting lenses and windows;

(2) Partitions, other than transparent panels needed to enhance cabin safety;

(3) Galley structure, including exposed surfaces of stowed carts and standard containers and the cavity walls that are exposed when a full complement of such carts or containers is not carried; and

(4) Large cabinets and cabin stowage compartments, other than underseat stowage compartments for stowing small items such as magazines and maps.

(e) The interiors of compartments, such as pilot compartments, galleys, lavatories, crew rest quarters, cabinets and stowage compartments, need not meet the standards of sub-paragraph (d) of this paragraph, provided the interiors of such compartments are isolated from the main passenger cabin by doors or equivalent means that would normally be closed during an emergency landing condition.

(f) Smoking is not allowed in lavatories. If smoking is allowed in any area occupied by the crew or passengers, an adequate number of self-contained, removable ashtrays must be provided in designated smoking sections for all seated occupants.

(g) Regardless of whether smoking is allowed in any other part of the aeroplane, lavatories must have self-contained removable ashtrays located conspicuously on or near the entry side of each lavatory door, except that one ashtray may serve more than one lavatory door if the ashtray can be seen readily from the cabin side of each lavatory served.

(h) Each receptacle used for the disposal of flammable waste material must be fully enclosed, constructed of at least fire resistant materials, and must contain fires likely to occur in it under normal use. The ability of the receptacle to contain those fires under all probable conditions of wear, misalignment, and ventilation expected in service must be demonstrated by test.

CS 25.854 Lavatory fire protection

ED Decision 2017/015/R

(See AMC 25.854)

For aeroplanes with a passenger capacity of 20 or more, or with a cabin length of 18.29 m (60 ft) or more:

(a) Each lavatory must be equipped with a smoke detector system or equivalent that provides a warning light in the cockpit, or provides a warning light or audible warning in the passenger cabin that would be readily detected by a cabin crew member; and

(b) Each lavatory must be equipped with a built-in fire extinguisher for each disposal receptacle for towels, paper, or waste, located within the lavatory. The extinguisher must be designed to discharge automatically into each disposal receptacle upon occurrence of a fire in that receptacle.

CS 25.855 Cargo or baggage compartments

ED Decision 2013/010/R

(See AMC 25.855 and 25.857)

For each cargo or baggage compartment, the following apply:

(a) The compartment must meet one of the class requirements of CS 25.857.

(b) The following cargo or baggage compartments, as defined in CS 25.857, must have a liner that is separate from, but may be attached to, the aeroplane structure:

(1) Class B through Class E cargo or baggage compartments; and

(2) Class F cargo or baggage compartments, unless other means of containing the fire and protecting critical systems and structure are provided.

(c) (1) Ceiling and sidewall liner panels of Class C cargo or baggage compartments, and ceiling and sidewall liner panels in Class F cargo or baggage compartments, if installed to meet the requirements of sub-paragraph (b)(2) of this paragraph, must meet the test requirements of Part III of Appendix F or other approved equivalent methods.

(2) Cockpit voice and flight data recorder systems, windows and systems or equipment within, or in the vicinity of, Class E cargo compartments shown to be essential for continued safe flight and landing according to CS 25.1309 must be adequately protected against fire. If protective covers are used, they must meet the requirements of Appendix F, Part III

(d) All other materials used in the construction of the cargo or baggage compartment must meet the applicable test criteria prescribed in Part I of Appendix F, or other approved equivalent methods.

(e) No compartment may contain any controls, lines, equipment, or accessories whose damage or failure would affect safe operation, unless those items are protected so that –

(1) They cannot be damaged by the movement of cargo in the compartment; and

(2) Their breakage or failure will not create a fire hazard.

(f) There must be means to prevent cargo or baggage from interfering with the functioning of the fire protective features of the compartment.

(g) Sources of heat within the compartment must be shielded and insulated to prevent igniting the cargo or baggage.

(h) Flight tests must be conducted to show compliance with the provisions of CS 25.857 concerning –

(1) Compartment accessibility;

(2) The entry of hazardous quantities of smoke or extinguishing agent into compartments occupied by the crew or passengers; and

(3) The dissipation of the extinguishing agent in Class C compartment or, if applicable, in Class F compartment.

(i) During the above tests, it must be shown that no inadvertent operation of smoke or fire detectors in any compartment would occur as a result of fire contained in any other compartment, either during or after extinguishment, unless the extinguishing system floods each such compartment simultaneously.

(j) Cargo or baggage compartment electrical wiring interconnection system components must meet the requirements of CS 25.1721.

CS 25.856 Thermal/acoustic insulation materials

ED Decision 2016/010/R

(See AMC 25.856(a))

(a) Thermal/acoustic insulation material installed in the fuselage must meet the flame propagation test requirements of Part VI of Appendix F to CS-25, or other approved equivalent test requirements. This requirement does not apply to "small parts", as defined in Part I of Appendix F to CS-25. (See AMC 25.856(a))

(b) For aeroplanes with a passenger capacity of 20 or greater, thermal/acoustic insulation materials (including the means of fastening the materials to the fuselage) installed in the lower half of the aeroplane fuselage must meet the flame penetration resistance test requirements of Part VII of Appendix F to CS-25, or other approved equivalent test requirements. This requirement does not apply to thermal/acoustic insulation installations that the Agency finds would not contribute to fire penetration resistance. (See AMC 25.856(b))

CS 25.857 Cargo compartment classification

ED Decision 2009/017/R

(See AMC 25.855 and 25.857)

(a) *Class A.* A Class A cargo or baggage compartment is one in which –

(1) The presence of a fire would be easily discovered by a crew member while at his station; and

(2) Each part of the compartment is easily accessible in flight.

(b) *Class B.* A Class B cargo or baggage compartment is one in which –

(1) There is sufficient access in flight to enable a crewmember standing at any one access point and without stepping into the compartment, to extinguish a fire occurring in any part of the compartment using a hand fire extinguisher;

(2) When the access provisions are being used no hazardous quantity of smoke, flames or extinguishing agent will enter any compartment occupied by the crew or passengers; and

(3) There is a separate approved smoke detector or fire detector system to give warning to the pilot or flight engineer station.

(c) *Class C.* A Class C cargo or baggage compartment is one not meeting the requirements for either a Class A or B compartment but in which–

(1) There is a separate approved smoke detector or fire detector system to give warning at the pilot or flight engineer station;

(2) There is an approved built-in fire-extinguishing or suppression system controllable from the cockpit.

(3) There are means to exclude hazardous quantities of smoke, flames, or extinguishing agent, from any compartment occupied by the crew or passengers; and

(4) There are means to control ventilation and draughts within the compartment so that the extinguishing agent used can control any fire that may start within the compartment.

(d) Reserved.

(e) *Class E.* A Class E cargo compartment is one on aeroplanes used only for the carriage of cargo and in which –

(1) Reserved.

(2) There is a separate approved smoke or fire detector system to give warning at the pilot or flight engineer station;

(3) There are means to shut off the ventilating airflow to, or within, the compartment, and the controls for these means are accessible to the flight crew in the crew compartment;

(4) There are means to exclude hazardous quantities of smoke, flames, or noxious gases, from the flight-crew compartment; and

(5) The required crew emergency exits are accessible under any cargo loading condition.

(f) Class F. A Class F cargo or baggage compartment is one in which -

(1) There is a separate approved smoke detector or fire detector system to give warning at the pilot or flight engineer station;

(2) There are means to extinguish or control a fire without requiring a crewmember to enter the compartment; and

(3) There are means to exclude hazardous quantities of smoke, flames, or extinguishing agent from any compartment occupied by the crew or passengers.

CS 25.858 Cargo or baggage compartment smoke or fire detection systems

ED Decision 2007/010/R

If certification with cargo or baggage compartment smoke or fire detection provisions is requested, the following must be met for each cargo or baggage compartment with those provisions:

(a) The detection system must provide a visual indication to the flight crew within one minute after the start of a fire.

(b) The system must be capable of detecting a fire at a temperature significantly below that at which the structural integrity of the aeroplane is substantially decreased.

(c) There must be means to allow the crew to check in flight, the functioning of each smoke or fire detector circuit.

(d) The effectiveness of the detection system must be shown for all approved operating configurations and conditions.

APPENDICES TO CS-25

Appendix F

Part I – Test Criteria and Procedures for Showing Compliance with CS 25.853, 25.855 or 25.869

ED Decision 2015/019/R

(a) *Material test criteria –*

(1) *Interior compartments occupied by crew or passengers.*

(i) Interior ceiling panels, interior wall panels, partitions, galley structure, large cabinet walls, structural flooring, and materials used in the construction of stowage compartments (other than underseat stowage compartments and compartments for stowing small items such as magazines and maps) must be self-extinguishing when tested vertically in accordance with the applicable portions of Part I of this Appendix. The average burn length may not exceed 15 cm (6 inches) and the average flame time after removal of the flame source may not exceed 15 seconds. Drippings from the test specimen may not continue to flame for more than an average of 3 seconds after falling.

https://www.easa.europa.eu/en/document-library/easy-access-rules/online-publications/easy-access-rules-large-aeroplanes-cs-25?page=68

FLAMMABILITY REQUIREMENTS FOR AIRCRAFT SEAT CUSHIONS   ANM-110   25.853-1

1. PURPOSE. This Advisory Circular (AC) provides guidance material for demonstrating compliance with the Federal Aviation Regulations (FAR) pertaining to flammability of aircraft seat cushions. This AC also defines certain terms used in the FAR, in the context of these requirements.

2. RELATED FAR SECTIONS.

a. Section 25.853 of Part 25 of the FAR - Compartment Interiors.

b. Appendix F--Part II, of Part 25 of the FAR - Flammability of Seat Cushions.

c. Section 29.853 of Part 29 of the FAR - Compartment Interiors.

d. Section 121.312 of Part 121 of the FAR - Materials for Compartment Interiors.

e. Section 135.169 of Part 135 of the FAR - Additional Airworthiness Requirements.

3. BACKGROUND.

a. On October 23, 1984, the Federal Aviation Administration (FAA) issued Amendments 25-59, 29-23, and 121-184 which became effective November 26, 1984. These amendments are part of the FAA's continuing efforts to upgrade aircraft cabin safety and improve occupant survivability

https://www.fire.tc.faa.gov/pdf/25-853.pdf

Airbus ABD0031

AIRBUS

ABD

ABD0031

Fireworthiness Requirements Pressurised Section of Fuselage

Table of contents

not online

Aircraft Fire Protection (ATA 26)

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

Skript zur Vorlesung

Version für: CC BY-NC-SA

Flugzeugsysteme

Prof. Dr.-Ing. Dieter Scholz, MSME

2013

Kapitel 7

Flugzeugsysteme

Dieter Scholz

Seiten 700–805

https://doi.org/10.3139/9783446436046.007

7.5 Feuerschutz

Zum **Feuerschutz** (*fire protection*, ATA 26) gehören die Einheiten und Komponenten, die Feuer und Rauch erkennen und anzeigen, die weiterhin Feuerlöschmittel speichern und in alle geschützten Bereiche weiter verteilen. Sie enthalten Flaschen, Ventile, Rohrleitungen usw. [ATA 100].

http://handbuch.ProfScholz.de

https://www.fzt.haw-hamburg.de/pers/Scholz/materialFSs/Skript2.html

https://www.fzt.haw-hamburg.de/pers/Scholz/paper/Bericht_1-06.pdf

Fire Protection (ATA 26)

Definition

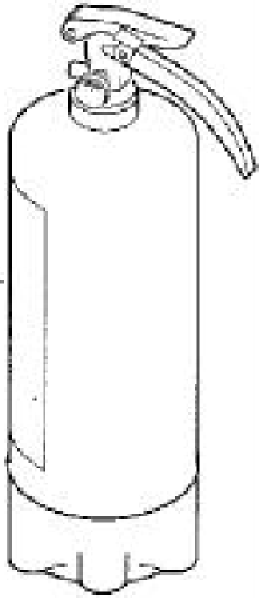
Those fixed and portable units and components which detect and indicate fire or smoke and store and distribute fire extinguishing agent to all protected areas of the aircraft; including bottles, valves, tubing, etc.

Source, original:
ATA, 1999. *Manufacturers' Technical Data (ATA Spec 100)*. Washington, D.C., USA: Air Transport Association of America (ATA).

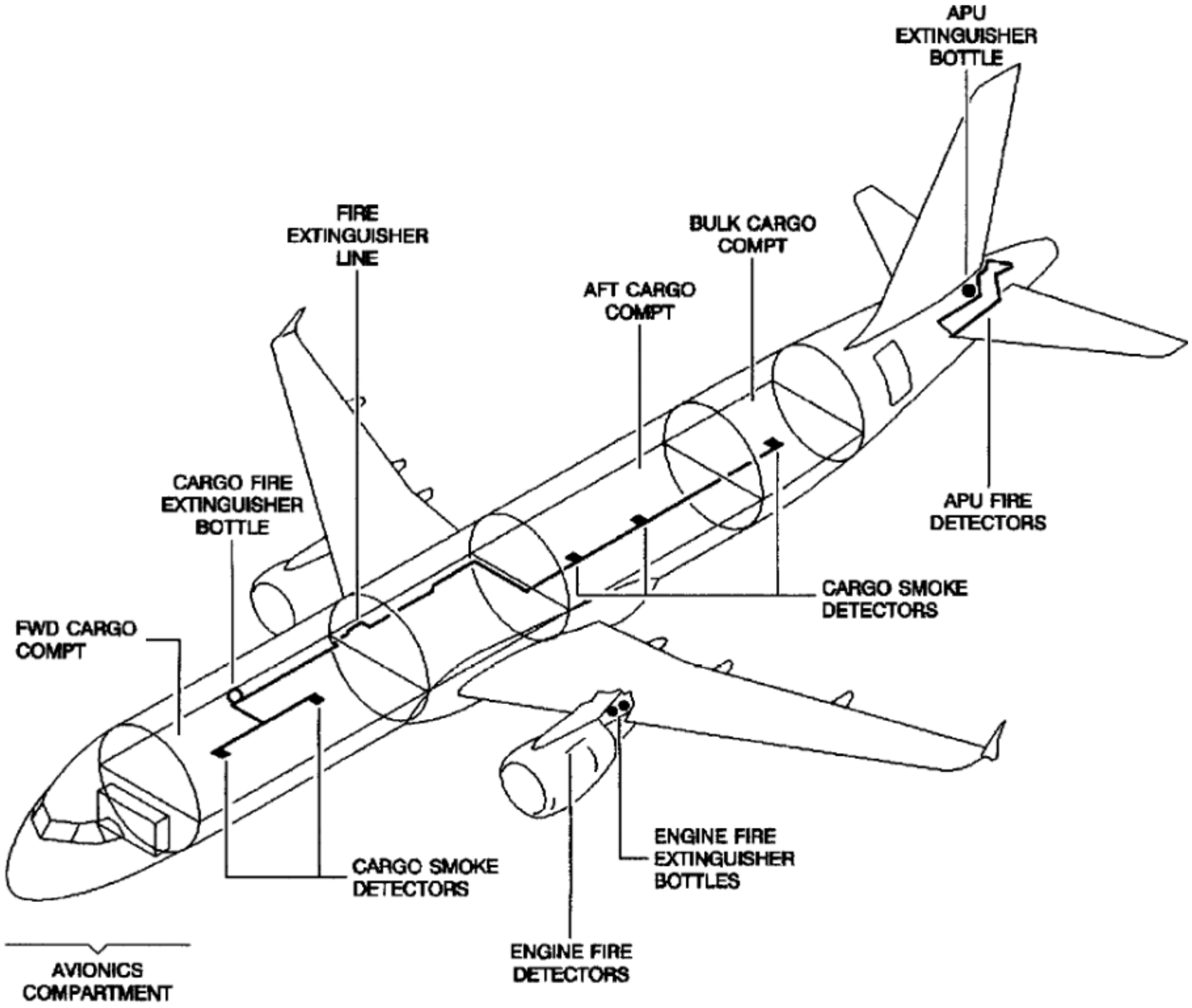
Source, today:
A4A, 2023. *iSpec 2200 Extract: ATA Standard Numbering System*. Washington D.C, USA: Airlines for America (A4A).
Available from: https://bit.ly/3PkrpMF (purchase information)
Archived at: https://perma.cc/T9ZX-S3SJ

The Aircraft fire protection system comprises:

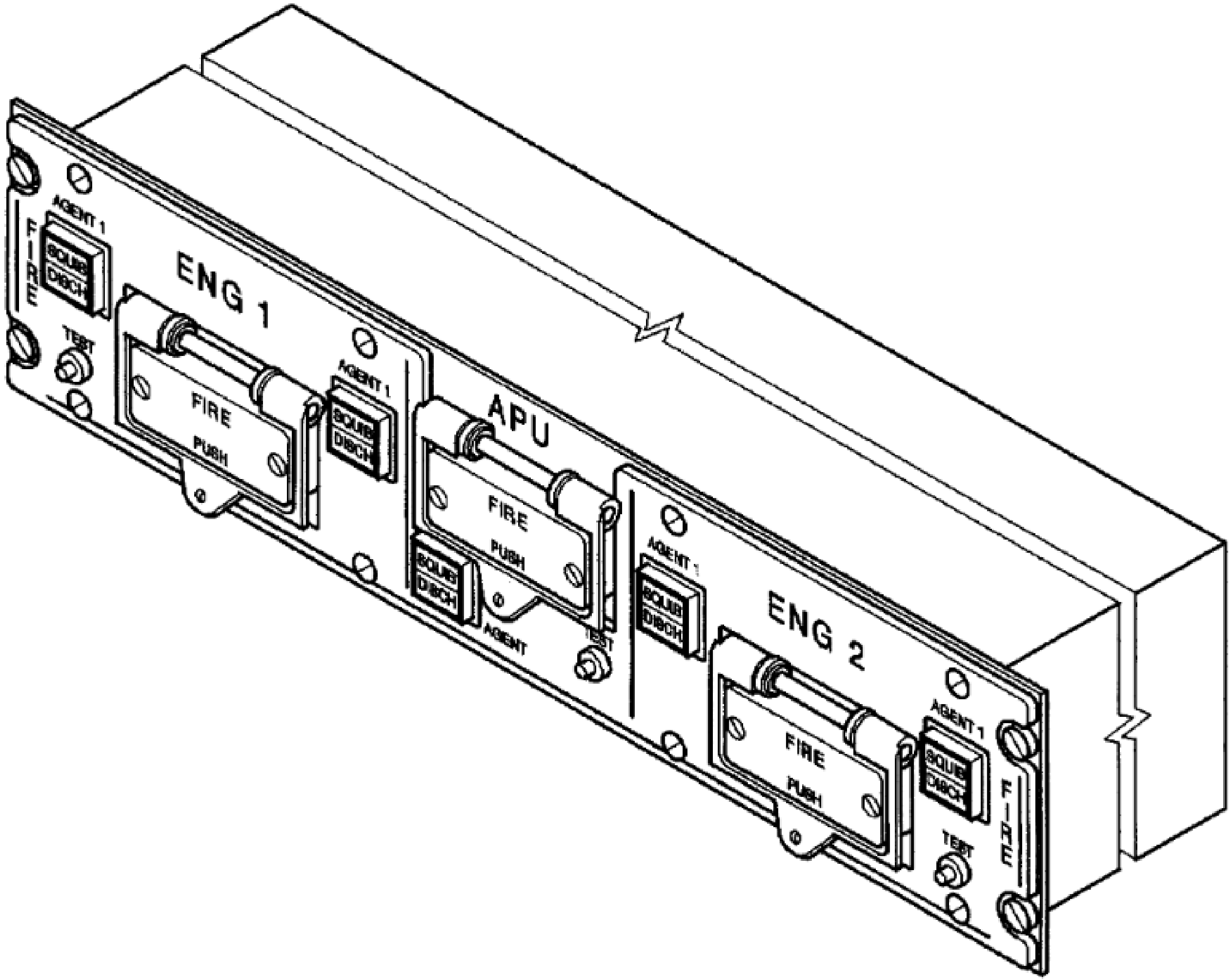
- fire and overheat detection and extinguishing system for
  - the engines,
  - the Auxiliary Power Unit (APU),
- smoke detection and extinguishing for
  - the cargo compartment (optional system),
  - the lavatories,
- smoke detection for
  - the avionic bay,
- portable fire extinguishers for
  - the flight compartment,
  - the passenger cabin.



Example
[Airbus A321]

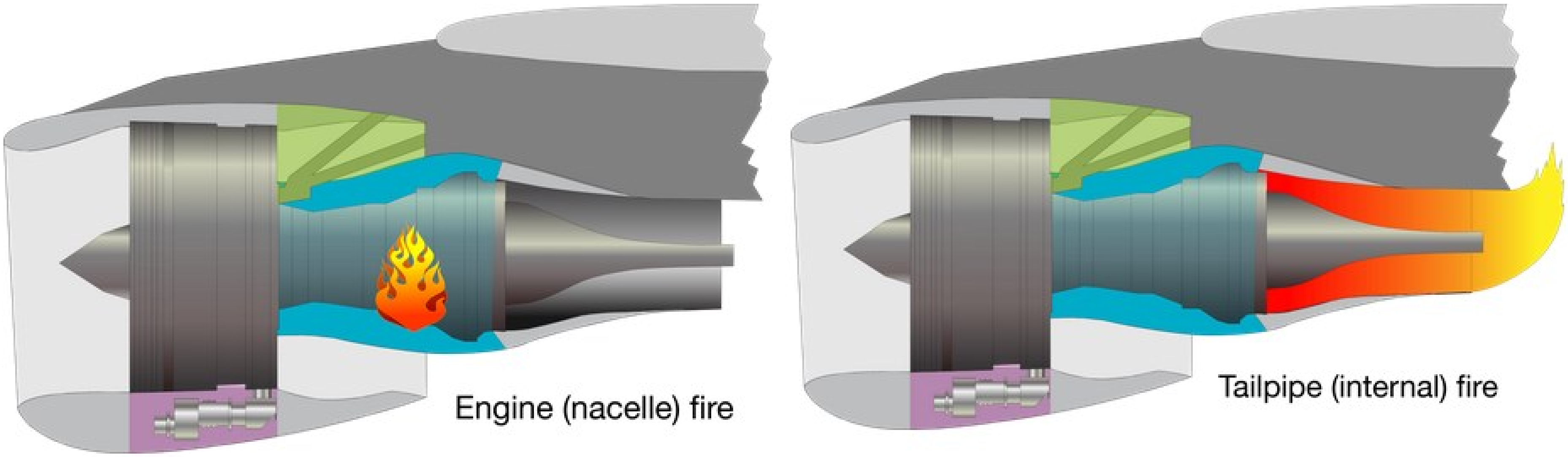


The fire protection system: component locations



Engine and APU fire overhead panel

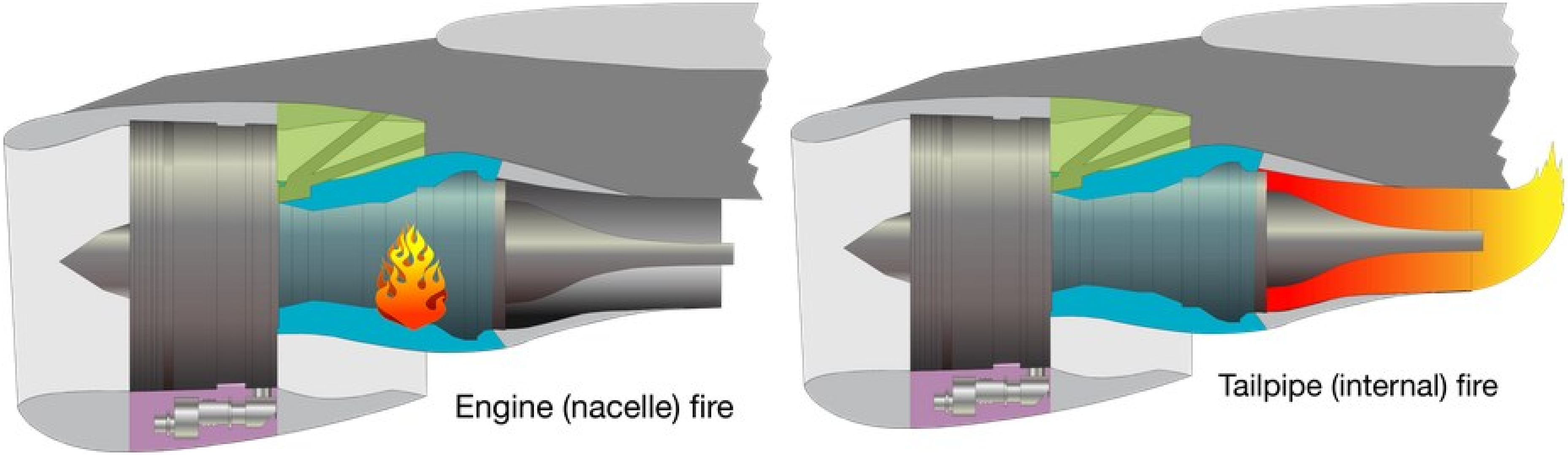
Source: https://safetyfirst.airbus.com/do-not-wait-to-apply-the-engine-fire-procedure



There are two types of engine fire: an engine fire (nacelle fire) and tailpipe fire (internal fire). Both types of fire affect the core but must be treated differently.

An **engine fire (nacelle fire)** affects the external part of the engine core but is contained within the engine nacelle. This type of fire can occur on ground or in flight and is usually caused by a malfunction or rupture of a component or pipe, which contains flammable liquids (high-pressure fuel, oil, hydraulic fluid). When these liquids come into contact with hot surfaces on the engine case, such as the high-pressure compressor, combustor, or turbine, they can self-ignite and cause a fire. This type of engine fire can also be caused by rupture of a part of the engine core causing damage to components and pipes, which can lead to a fire.

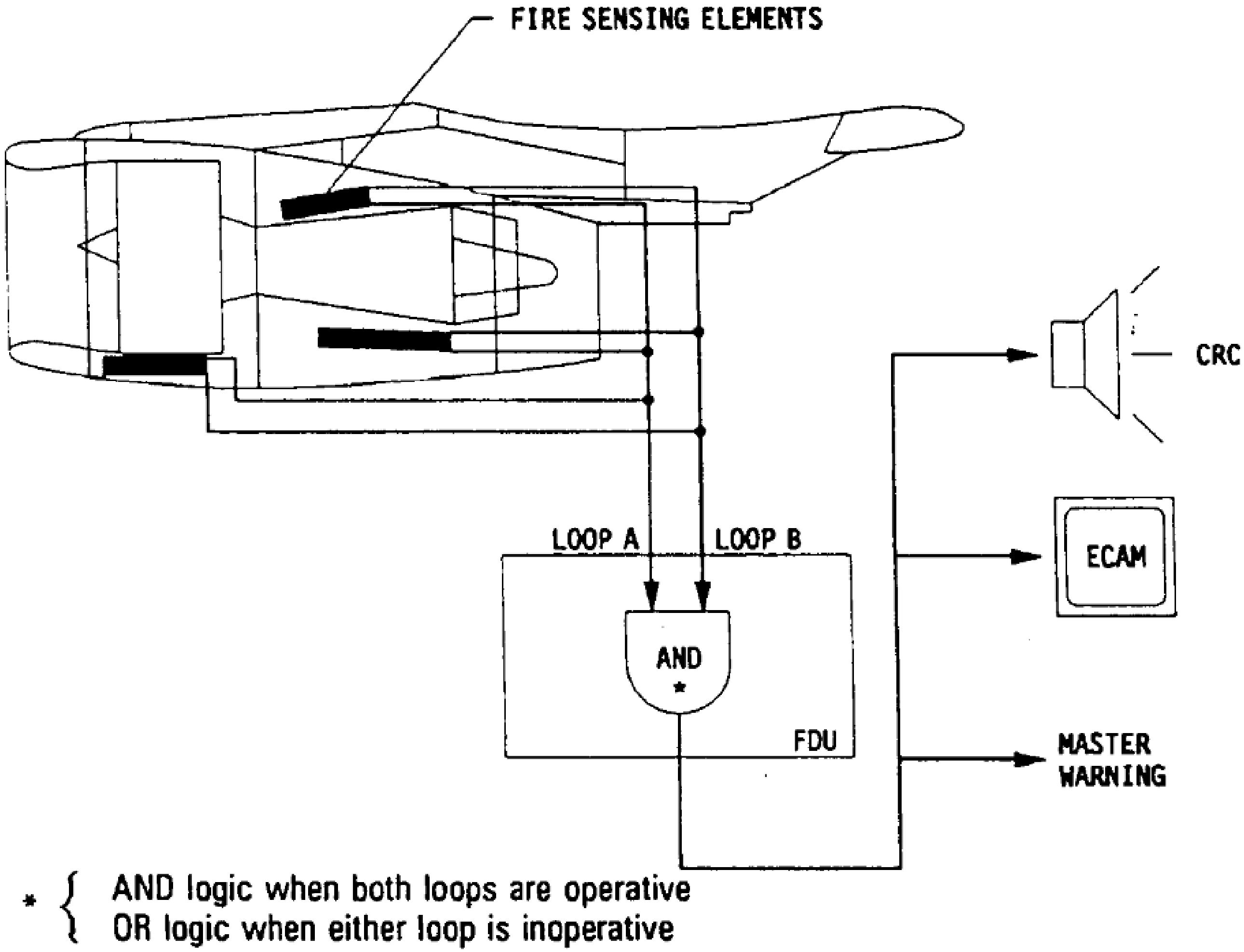
Source: https://safetyfirst.airbus.com/do-not-wait-to-apply-the-engine-fire-procedure



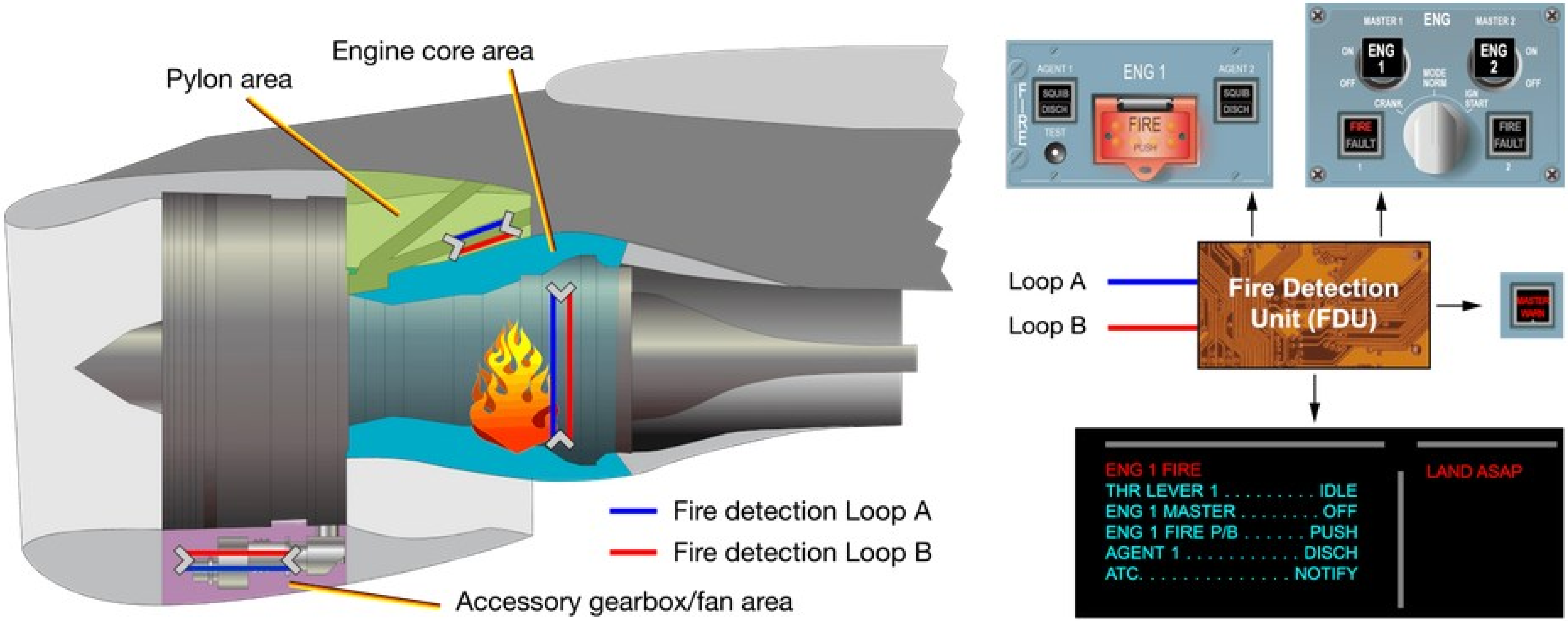
A **tailpipe fire (internal fire)** occurs inside the engine core. This type of fire will only occur during the engine start or shutdown sequence. A tailpipe fire occurs when the engine rotates at a very low speed and residual fuel is present in the combustion chamber or turbine area, or if there is an oil leak in the tailpipe of the engine. The risk of tailpipe fire is higher in the case of a second engine start attempt, because residual fuel may remain in the engine after the first attempted engine start.

The fire detection system does not detect tailpipe fires, because they occur inside the hot sections of the engine core, and therefore, are outside of the fire detection zone. Flight crews can detect tailpipe fires by observing any abnormal increase in Exhaust Gas Temperature (EGT) during the engine start sequence or if the EGT does not decrease after engine shutdown. Ground crew, cabin crew, or air traffic controllers may also observe a tailpipe fire and must inform the flight crew.

In the case of a tailpipe fire, the flight crew must apply the ENGINE TAILPIPE FIRE abnormal procedure from the QRH. This will ventilate the engine, and the airflow will extinguish the fire and remove any residual fuel or vapor from the engine.

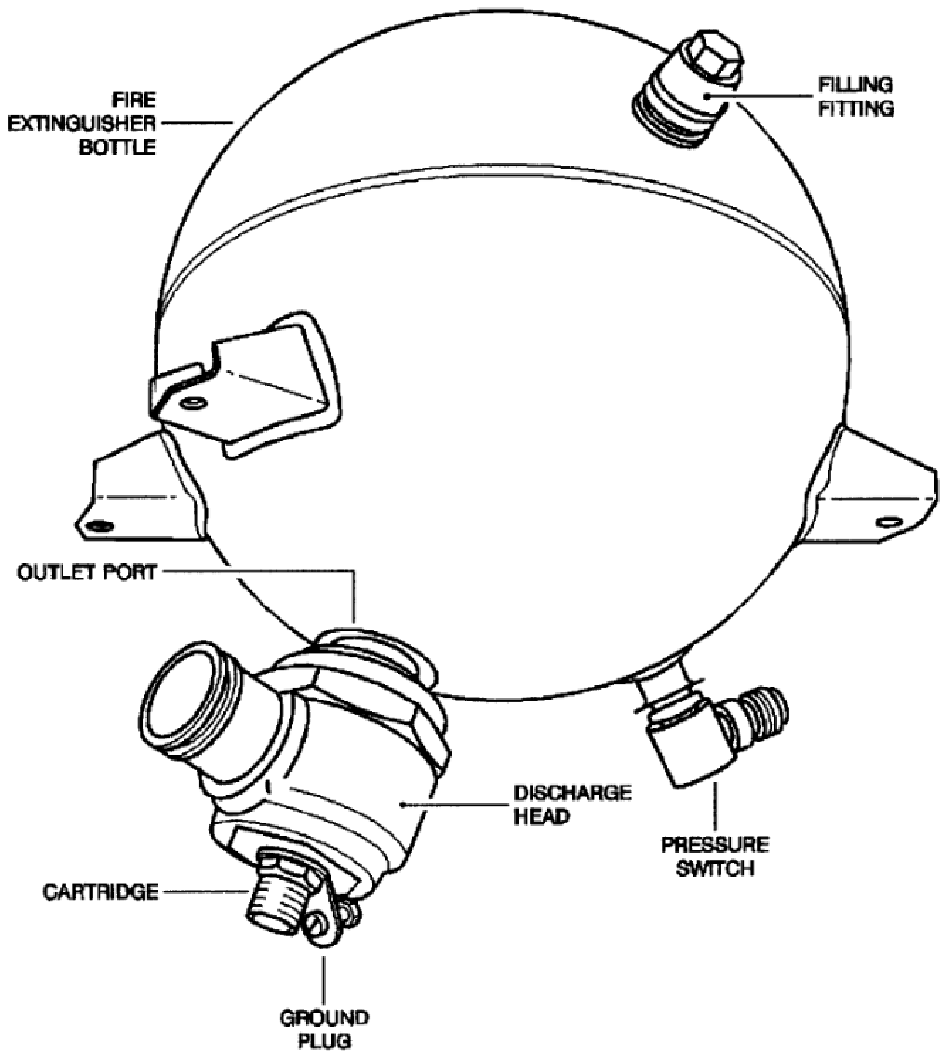


Engine fire detection logic

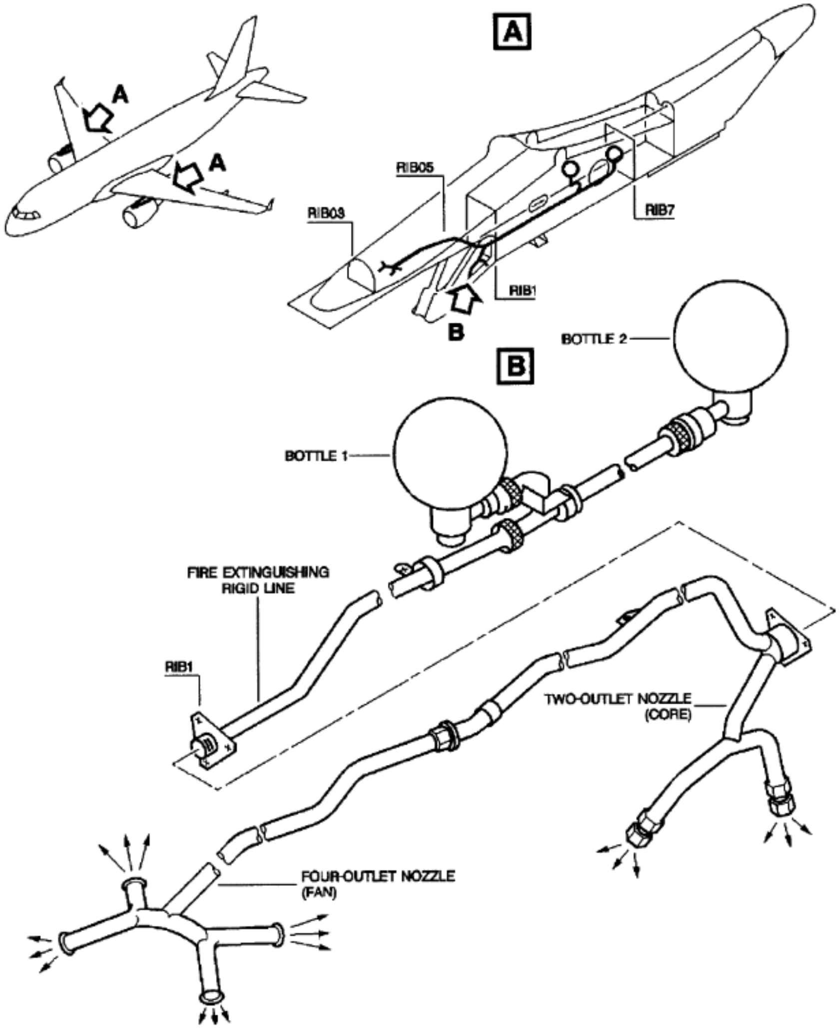


Example of engine fire detection system on an A320 aircraft with CFM engines.

Source: https://safetyfirst.airbus.com/do-not-wait-to-apply-the-engine-fire-procedure



A fire extinguisher bottle



The engine fire extinguishing distribution system

Engine fire extinguishing procedure: The list of actions to be done during the fire extinguishing procedure comes into view automatically on the ECAM display unit at the same time as the FIRE warnings. As soon as the required actions are done, the corresponding line is canceled automatically on the ECAM display unit. The following procedure must be applied:

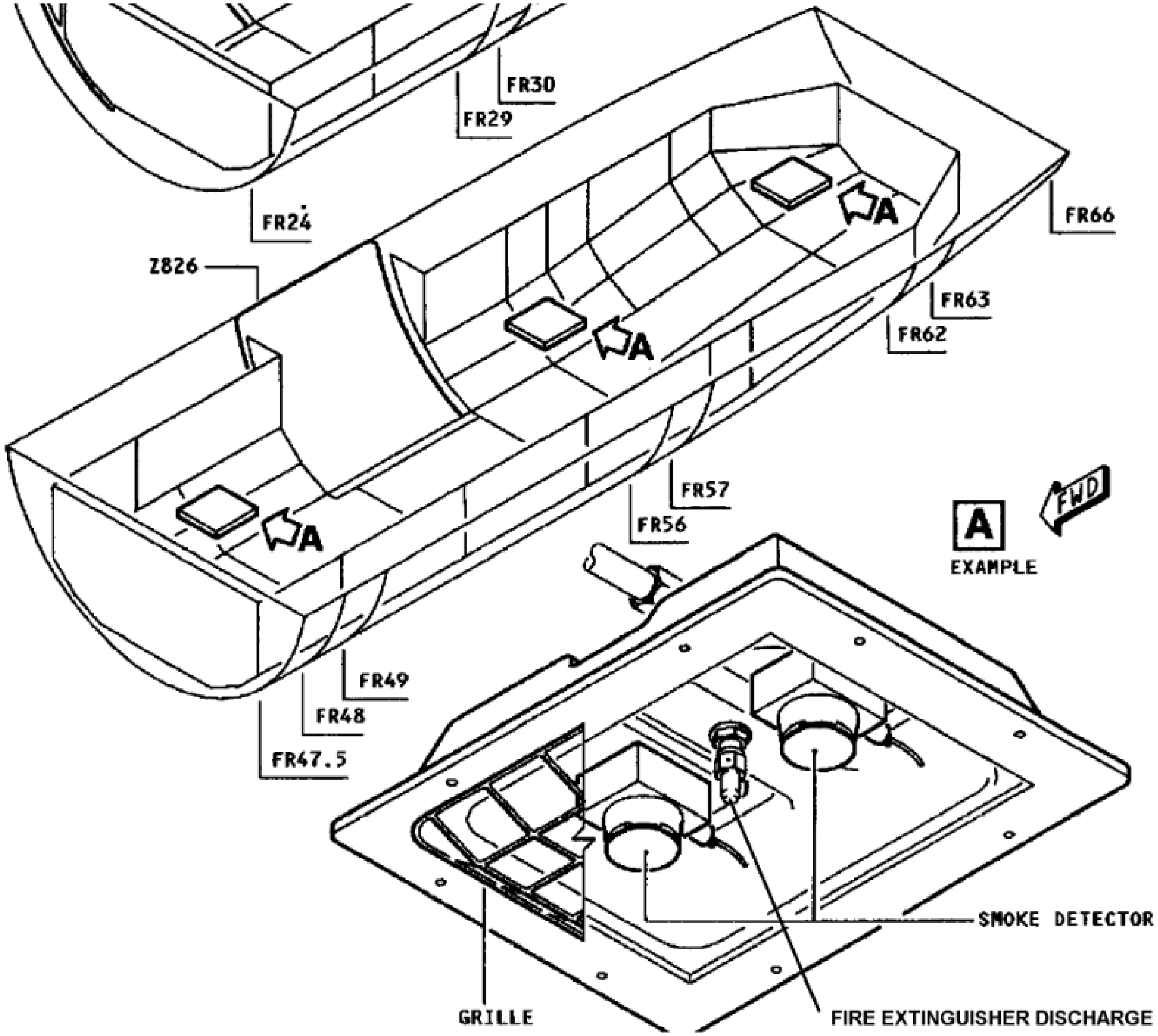
THR LEVER 1 ....IDLE	Throttle control lever in the Idle position
ENG MASTER 1............................OFF	ENG/MASTER switch in the OFF position
ENG 1 FIRE P/B ....PUSH	Push the ENG/FIRE push button switch
AGENT 1 AFTER 10 S..................DISCH	Wait 10 seconds for optimum extinguishing procedure
AGENT 1......................................DISCH	Squib the fire extinguisher bottle 1
ATC...NOTIFY	Send a distress signal to Air Traffic Control (ATC)
IF FIRE AFTER 30 S: AGENT 2....DISH	The second fire extinguisher bottle is fired, if the FIRE legend is still ON

Avionics compartment smoke procedure: The list of the necessary actions during the smoke procedure comes into view automatically on the lower ECAM display unit while the SMOKE warnings are triggered. When these actions are completed, the related lines are canceled automatically on the lower ECAM display unit. The procedure below must be applied:

IF PERCEPTIBLE SMOKE		
OXY MASK/GOGGLES	ON	
CAB FANS	OFF	to keep smoke off the cockpit and cabin
BLOWER	OVRD	(see above)
EXTRACT	OVRD	(see above)

An electrical procedure is applied to eliminate the cause of the smoke if the smoke emission persists more than 5 minutes.

IF SMOKE AFTER 5MNS:		
GEN 1 LINE	OFF	on EMER ELEC PWR overhead panel
EMER ELEC PWR	MAN ON	on EMER ELEC PWR overhead panel: Ram Air Turbine extension



Cargo compartment smoke detection and extinguishing component location

Critical Views: RAeS FOG

Safety in the Cabin – Past, Present and Future

Pete Terry and Dai Whittingham
RAeS Flight Operations Group

https://doi.org/10.5281/zenodo.5596659

This presentation is based upon 2 papers published (2018) by the Flight Operations Group:

Emergency Evacuation of Commercial Passenger Aeroplanes (2018)

https://www.aerosociety.com/media/8534/emergency-evacuation-of-commercial-passenger-aeroplanes-paper.pdf

Smoke, Fire and Fumes in Transport Aircraft
Part 1: Reference (2018)

https://www.aerosociety.com/media/9215/safita_part-1_v5.pdf

- **EASA 2009 CS 25 Study:**

Further research into seat space might be required to:

> **"…**investigate the **effects of various seat spacing dimensions on evacuation,** not just on the passengers' **ease of egress** but also on the **overall dynamics** of the emergency evacuation**."**
>
> "The investigation should also take into account the **projected increasing proportion of elderly people** in the flying population and people from the **higher dimension percentile group."**

- **No further EASA action since 2009 Study**

- However, in 2015 EASA stated:

  *"....that the data presently at (its) disposal is **not sufficient to justify legislative measures on seat pitch** at the EU level."*

and:

  *"...(this is a) **commercial decision taken by the airlines in a competitive market,** who are free to offer different levels of service and to charge different fees for them."*

- July 2018, USA Court of Appeals Circuit judge files opinion requiring the FAA to consider developing requirements for a minimum seat space.
- The FAA responded that it **would not regulate airline seat space** and legroom, and that **current seat size was not a safety issue**

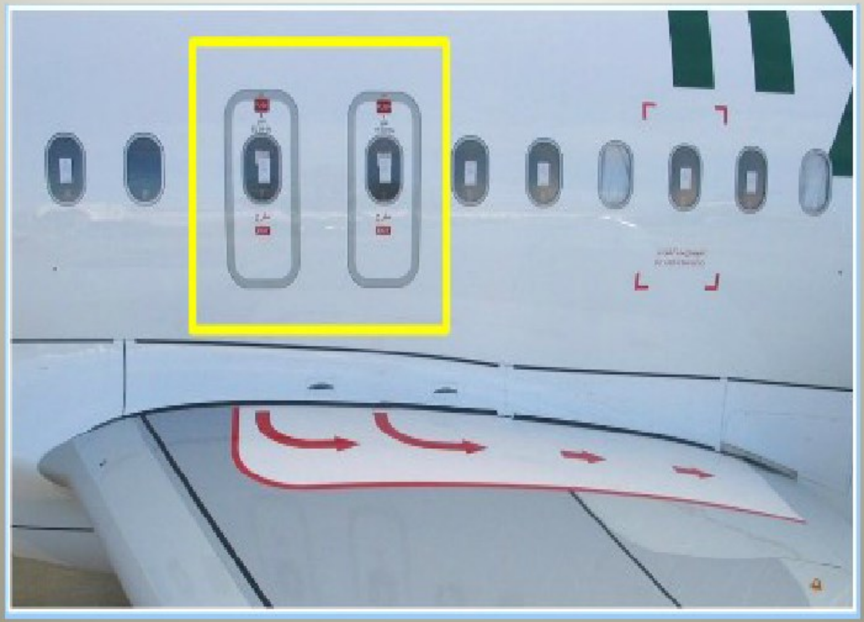
The International Branch for Research into Aircraft Crash Events [IBRACE] has concluded that with seat pitches of **less than 30 inches** an average passenger would be unable to adopt the recommended brace position.

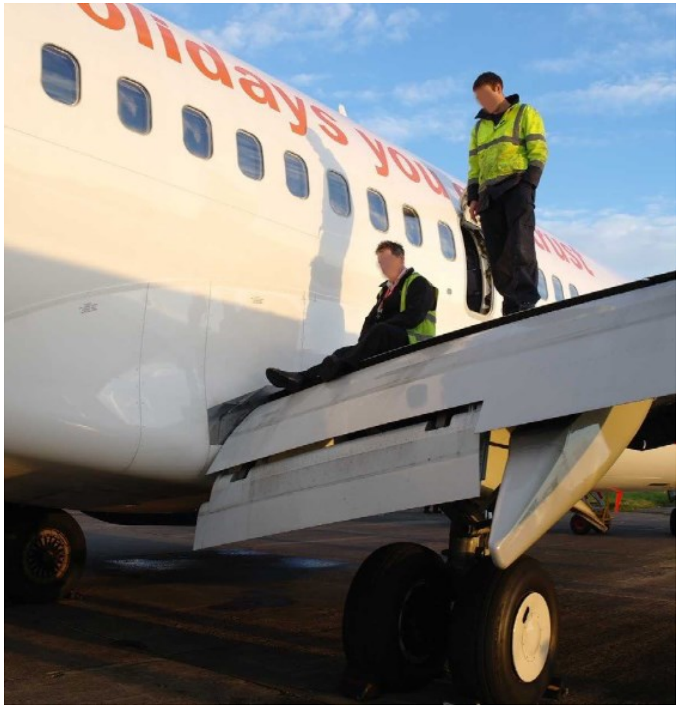
- All new-build aeroplanes should, where relevant, be equipped with improved Type III exits

- Where practicable, older Type III exits should be replaced with the improved versions

July 2013 - Asiana Airlines - Boeing 777-200 - San Francisco, USA

- **Certification test requirement:** all passengers and crew to be on the ground within **90 seconds** and with only **50% of exits** available.
- Evacuation time influenced by number/location of exits, number of passengers, external conditions (fire, debris) and internal damage.


Airbus A320 wing markings



- 1.8m/6ft drop = slide required
  - Arbitrary! Testing, provenance?
  - Aged/infirm? Young?

Airbus A320 off-wing slide

My bag is worth more to me than your life...

Lockable overhead bins?

Baggage considered in certification testing?

Conclusions

- Many improvements in the last 30 years
  - occupant safety has been enhanced
- Commercial pressures directly affect operational safety
- Toxic/flammable materials was the killer in the 70's/80's, cabin baggage is today's threat in otherwise survivable accidents
- Tombstone regulation is unacceptable!

Aircraft Fire and Evacuation Simulation

Prof. Edwin Galea,
Director, Fire Safety Engineering
Group, University of Greenwich

https://doi.org/10.5281/zenodo.10730716

Evacuation Test, Airbus A380, 26.03.2006

https://youtu.be/d8sADF8ca-k

https://youtu.be/G_8hbsWKoOU

EASA CS-25.803 Emergency Evacuation

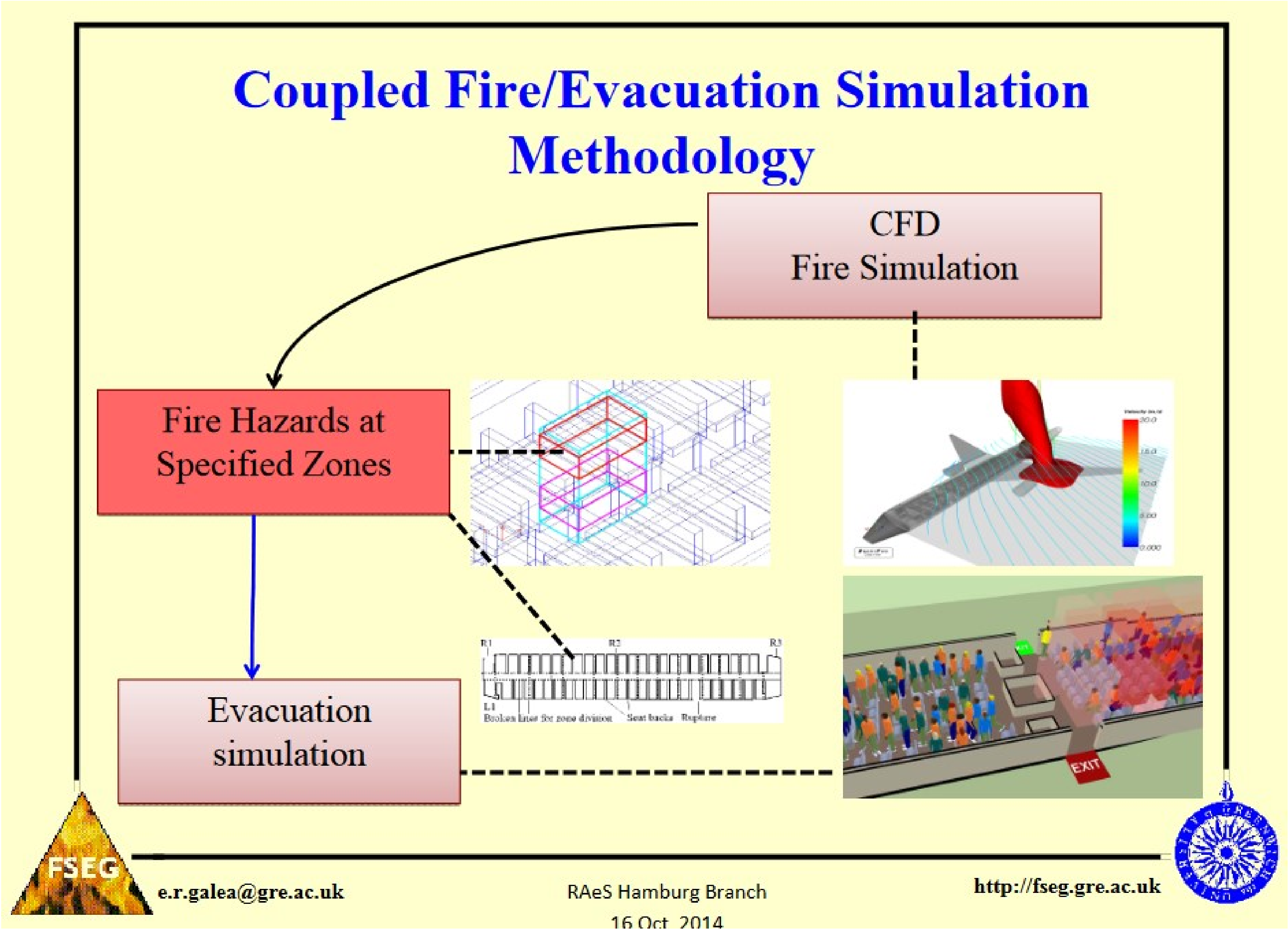
(a) Each crew and passenger area must have emergency means to allow rapid evacuation in crash landings, with the landing gear extended as well as with the landing gear retracted, considering the possibility of the aeroplane being on fire.

(b) Reserved.

(c) For aeroplanes having a seating capacity of more than 44 passengers, it must be shown that the maximum seating capacity, including the number of crew members required by the operating rules for which certification is requested, can be evacuated from the aeroplane to the ground under simulated emergency conditions within **90 seconds**. Compliance with this requirement must be shown by actual demonstration using the test criteria outlined in Appendix J of this CS-25 unless the Agency find that a combination of analysis and testing will provide data equivalent to that which would be obtained by actual demonstration.

Exploring the Appropriateness of the Aviation Industry Evacuation Certification Requirements Using Fire and Evacuation Simulation

Prof Ed Galea
Fire Safety Engineering Group (FSEG)
University of Greenwich



Coupled Fire/Evacuation Simulation Methodology
CFD
Fire Simulation
Fire Hazards at Specified Zones
Evacuation simulation
EXIT
FSEG
e.r.galea@gre.ac.uk
RAeS Hamburg Branch
16 Oct 2014
http://fseg.gre.ac.uk

EVACUATION CERTIFICATION

- **International Evacuation Certification Trial requires:**
  - *50% of exits available, one from each exit pair.*
    - It is assumed that post-crash external fire occurs on one side of the aircraft and so it is further assumed that all the exits on that side of the aircraft are unavailable.
  - *90 seconds maximum allowable time for evacuation.*
    - It is assumed that after 90 seconds, conditions inside the cabin are non-survival or that flashover has occurred.
  - *Applied to all passenger aircraft.*
    - Size or configuration of aircraft irrelevant, so same rules apply to A320 and A380.

FAA test 1989

Manchester, UK

22/08/85

FSEG

e.r.galea@gre.ac.uk

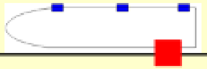
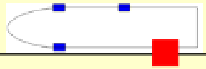
RAeS Hamburg Branch

16 Oct 2014

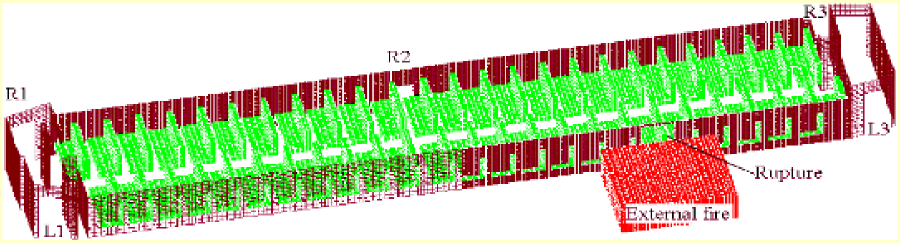
http://fseg.gre.ac.uk

TWO EXIT SCENARIOS

Two Exit Scenarios are considered:

Scenario	S1 	S2 
Open exits	R1, R2 and R3	R1, R2 and L1

- S1: normal certification exit configuration
- S2: exit combinations commonly found in real accidents, e.g. Manchester Airport B737 fire, 1985.



Cabin configuration

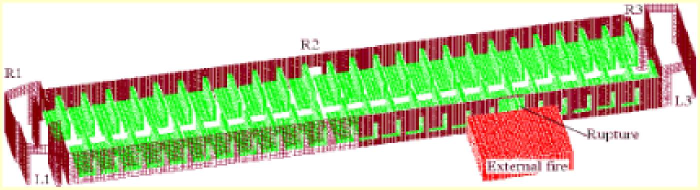
FIRE SIMULATION SET UP

Geometry Set Up

- External fire volume is 2.5m by 3.0m; HRR 7.8 MW, so that flame temp are close to experimental values of 1,480 K
- Mesh: 149,496 computational cells
- Red: external fire volume; Green: seats; Brown: walls; overhead bins removed for good visualization

Fire Models

- **Flame spread model** for ignition of solid surfaces;
- **Eddy Dissipation Combustion model** for release of heat due to combustion of gas fuel generated by pyrolysis of solid materials;
- **48-ray Radiation model** for exchange of heat due to radiation;
- **Toxicity model** for the generation and transportation of toxic fire gases;



SMARTFIRE set up

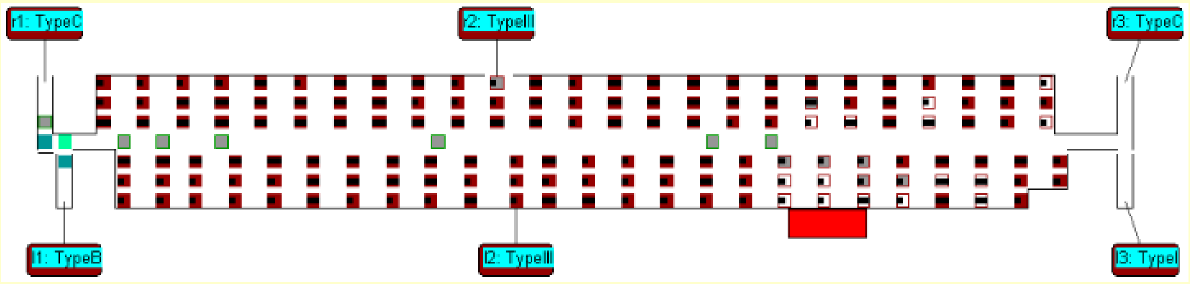
e.r.galea@gre.ac.uk

RAeS Hamburg Branch
16 Oct 2014

http://fseg.gre.ac.uk

IMPACT OF OPEN EXITS ON EVACUATION

Scenario	Number of fatalities	Time for first fatality (s)	Time for last fatality (s)	Average Distance (m)
S1	1.2	31.8	35.9	3.4
S2	14.6	28.2	248.6	12.3



Starting location (open symbols) and death locations (grey symbols) for a single S2 simulation

- **1.2 fatalities in S1**
  - Located in seats adjacent to the rupture, died of heat from external fire, with a short survival time/travel distance;
- **14.6 fatalities in S2**
  - Located in the rear of the cabin, died on the seats near the rupture, aisle, and places near the exits; with longer survival times/travel distances

S2 is more challenging than S1

e.r.galea@gre.ac.uk

RAeS Hamburg Branch
16 Oct 2014

http://fseg.gre.ac.uk

DEUTSCHE GESELLSCHAFT FÜR LUFT- UND RAUMFAHRT – LILIENTHAL-OBERTH E.V.
Wissenschaftlich - Technische Vereinigung

Permanent Link: http://dx.doi.org/10.6084/m9.figshare.1356339
https://www.fzt.haw-hamburg.de/pers/Scholz/dglr/hh/report_2014_10_16_Fire_and_Evacuation.pdf

Dieter Scholz, 2014

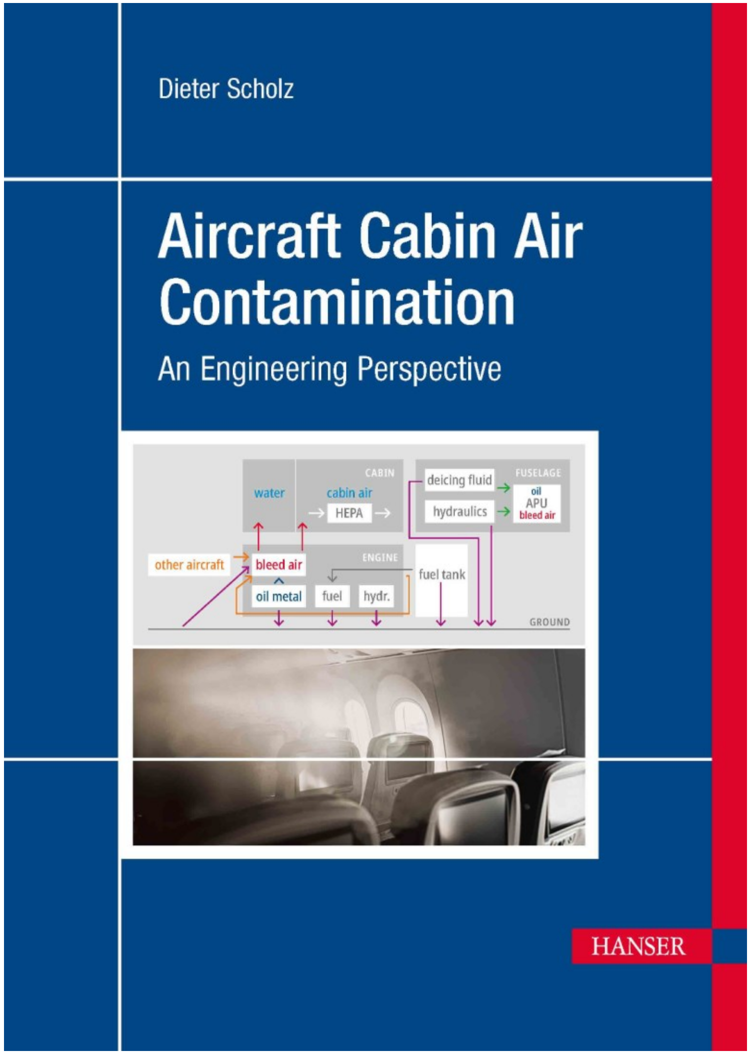
Prof. Galea Warns: Certification Rules for Aircraft Evacuation are not Adequate

Prof. Edwin Galea concludes:

- Current certification rules are inappropriate as a safety indicator as they are not representative of likely survivable accident exit configurations.
- Current certification rules are inappropriate as a safety indicator as they are not a sufficiently challenging exit configuration.
- Modeling should also be used for certification analysis and used to investigate additional exit configurations and additional repeat cases (different certification compliant populations; randomized passenger seating allocation).
- The 90-second-rule is arbitrary. Instead coupled fire and evacuation simulations can provide more insight into the fire safety of aircraft cabins.

Fume Events /
Cabin Air Contamination Events
(CACE)

http://CabinAir.ProfScholz.de



https://www.amazon.de/dp/3446482059

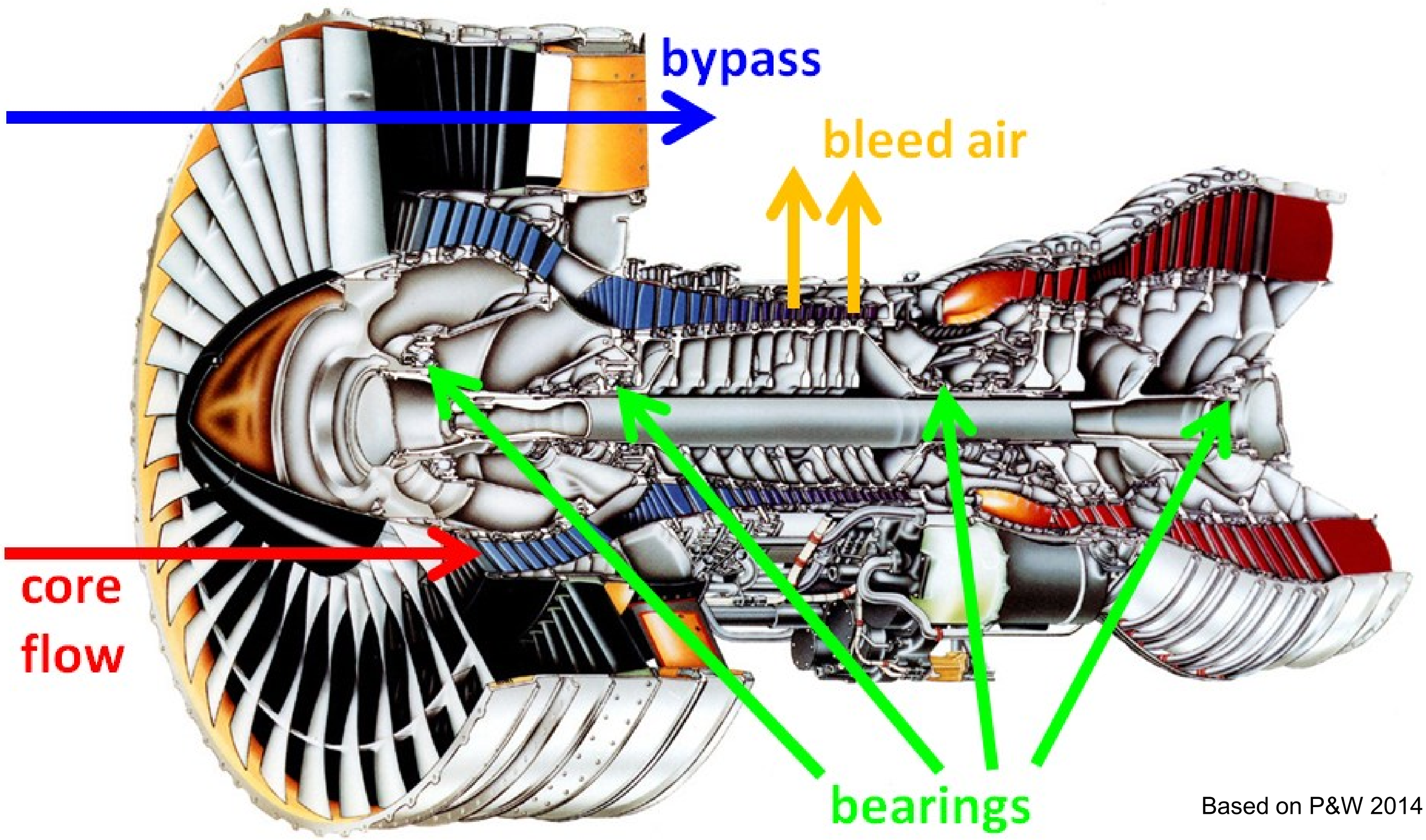
https://d-nb.info/132870338X

Purpose – This text is written to bring the engineering explanations of aircraft cabin air contamination together in one place and on another level of detail. Explanations go into technical detail, but all interested parties and people from all disciplines should benefit. --- **Methodology** – It is a review of the evidence combined with own contributions to the field. --- **Findings** – At a closer look, the aircraft is anything else but a glamorous polished machine. For technical reasons, dangerous chemicals are in use. These substances leave their intended places and get distributed everywhere. As such they just follow the law of nature: entropy. Unfortunately, while spreading, the substances also arrive in the human body with health and flight safety consequences. All occupants are potentially affected, but predominantly the crew, who spend much more time in an airplane than even a frequent flyer. In this way low dose exposures accumulate and are potentially topped by a high dose exposure in a failure case. --- **Research Limitations** – Focus is on cabin air contamination from engine oil in transport category airplanes. Contamination due to hydraulic fluid, deicing fluid, and even ozone is also considered. --- **Practical Implications** – People who suffer from consequences of aircraft cabin air contamination may find answers to the main question: Why? Others may find hints on how to get protected. --- **Social Implications** – This text can prove evidence of the engineering fundamentals in court. **Originality** – No comparable text seems to be published.

https://www.fzt.haw-hamburg.de/pers/Scholz/AircraftCabinAirContamination_Flyer.pdf

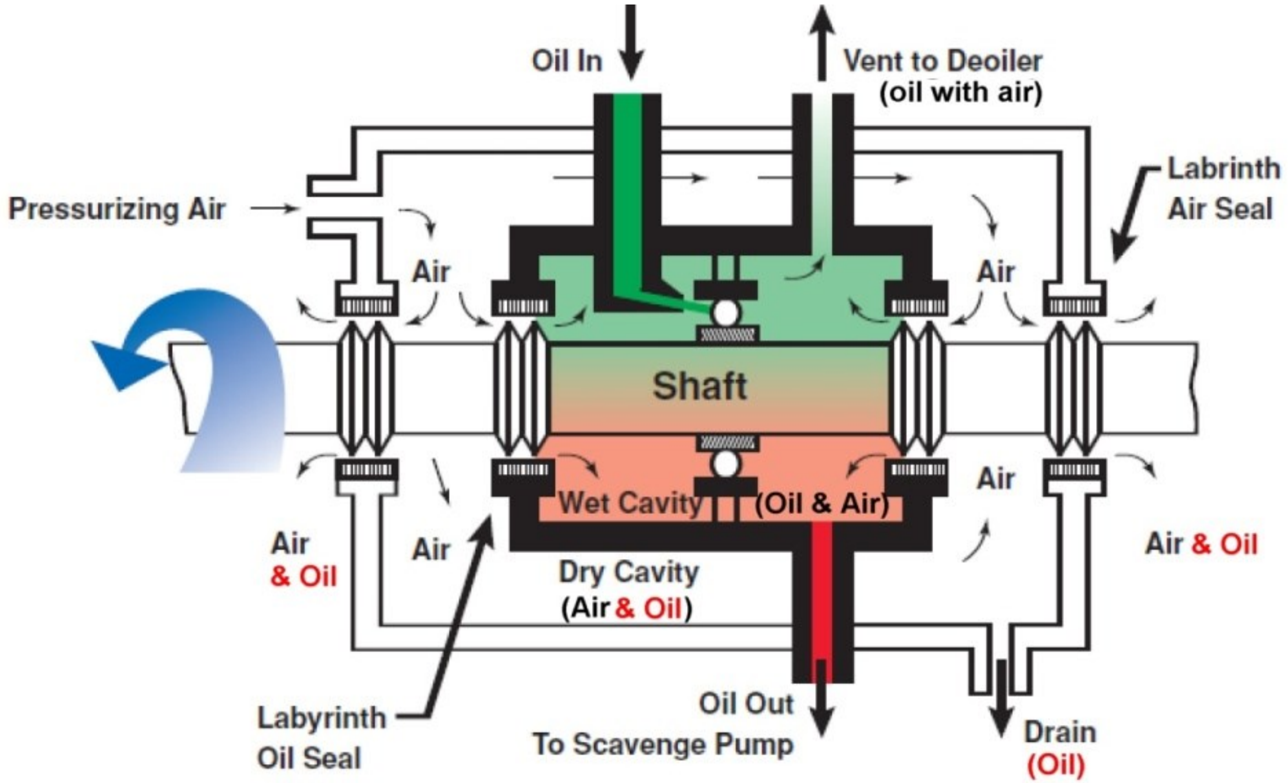
From the Jet Engine into the Cabin

Engine Bearings and Bleed Air



Based on P&W 2014

Lubrication and Sealing of Engine Bearings



Based on Exxon 2017

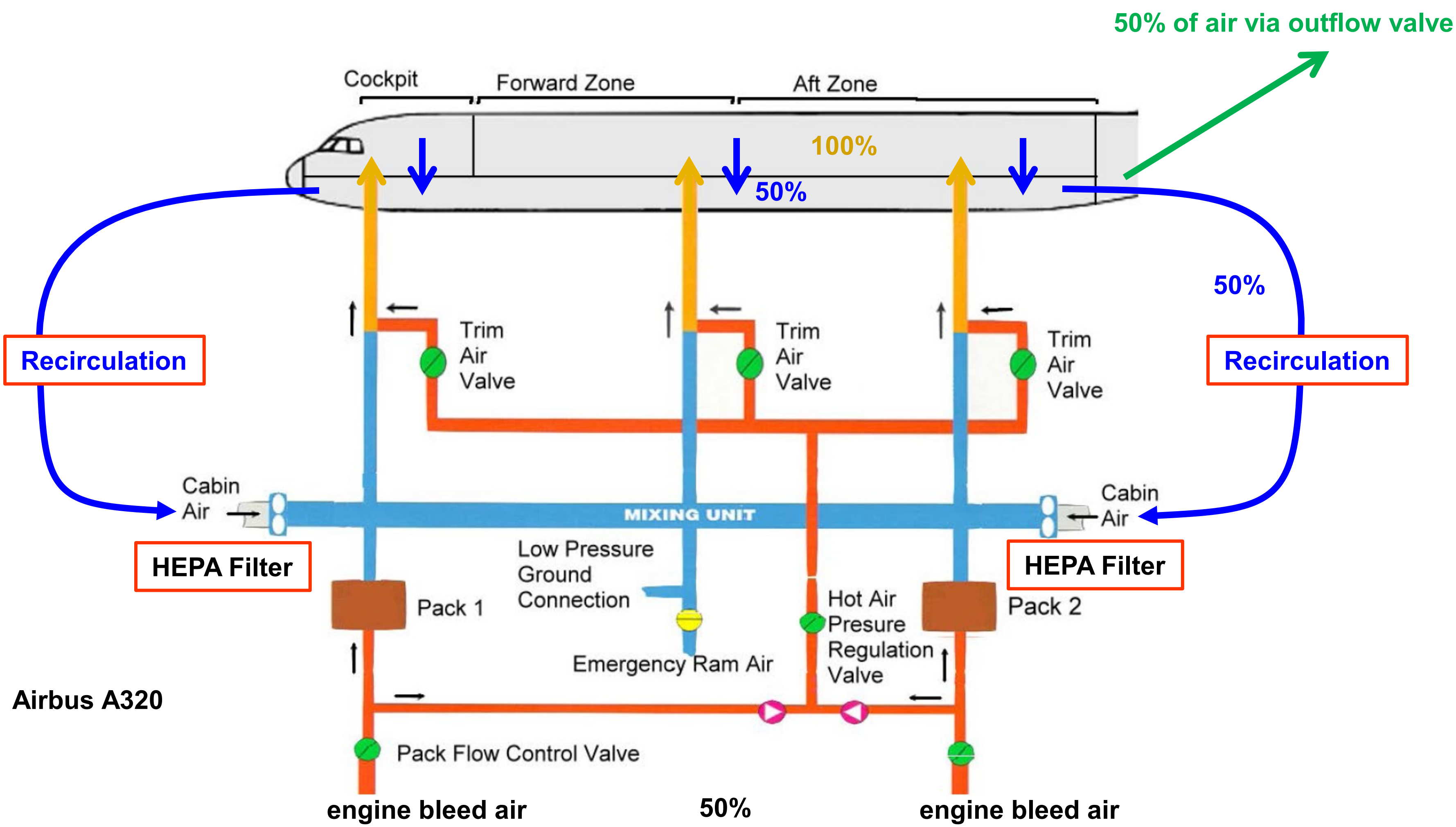
Normal operation of engine seals:

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!**

From the Jet Engine into the Cabin

Air Conditioning System



Airbus A320

Distribution of Fluids

Engine Oil

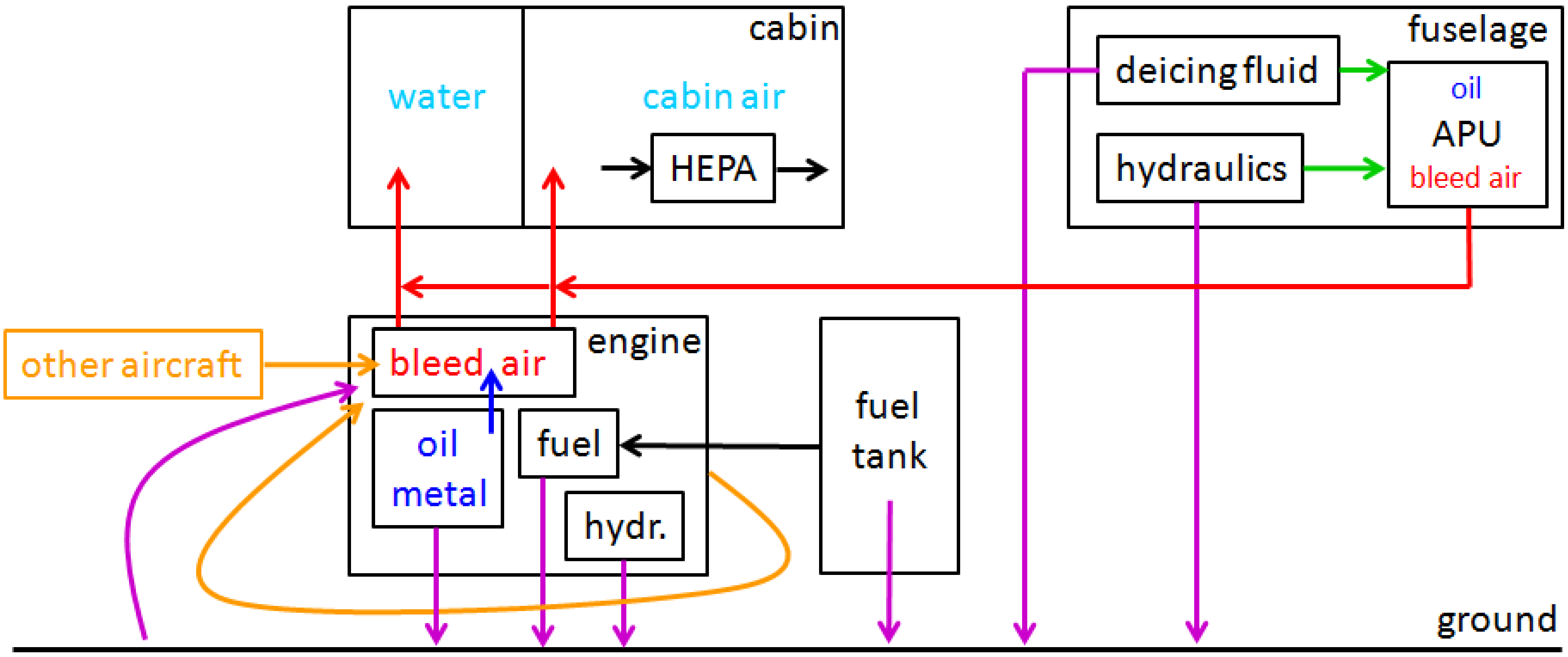
Hydraulic Fluid

Deicing Fluid

Fuel

Distribution of Fluids

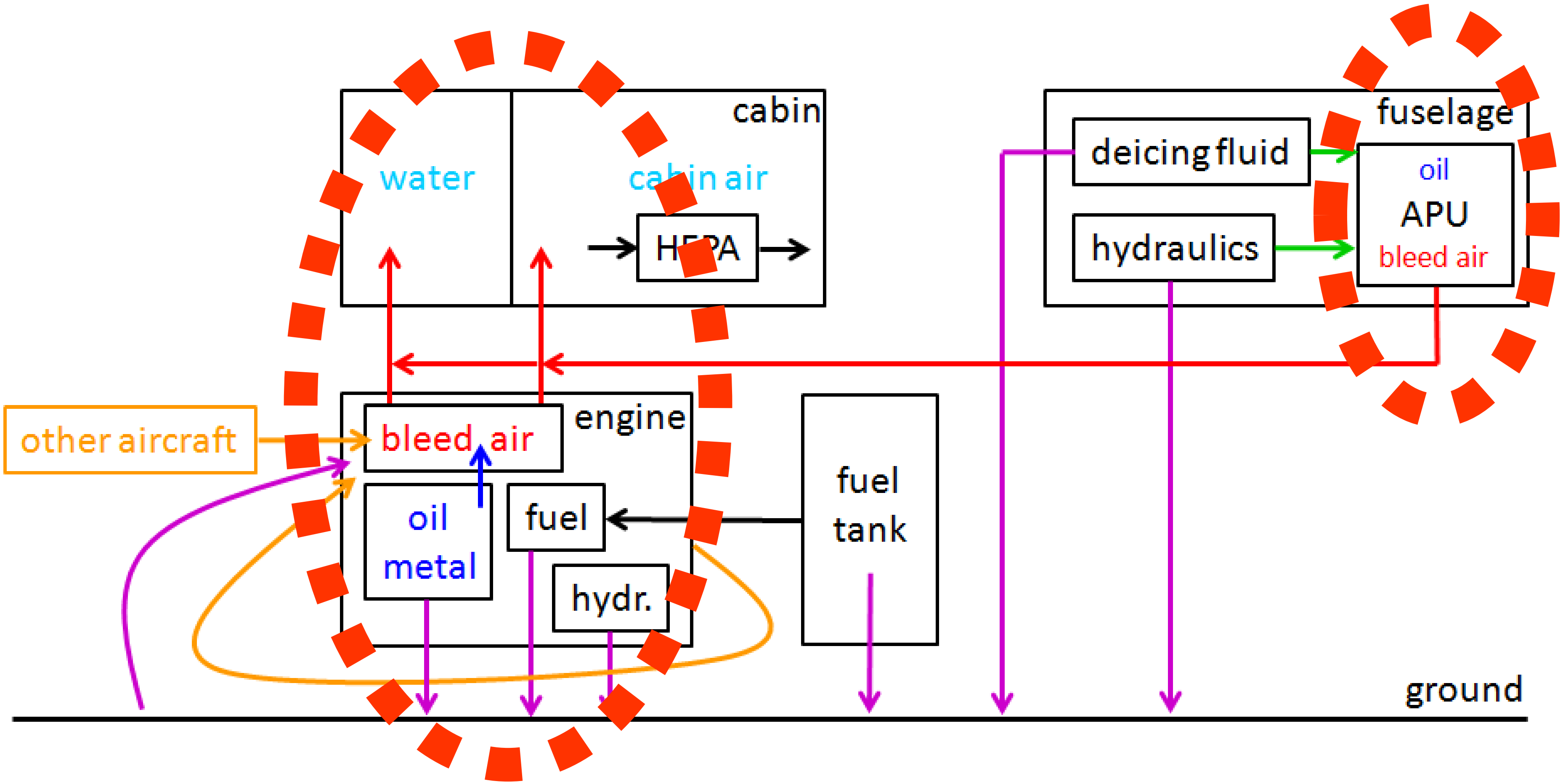
Contaminants and Their Routes Into the Cabin



Distribution of Engine Oil

Distribution of Engine Oil

The Route of Engine Oil Into the Cabin



Distribution of Engine Oil

Cabin Air Contamination Event Due to Engine Oil After Technical Fault

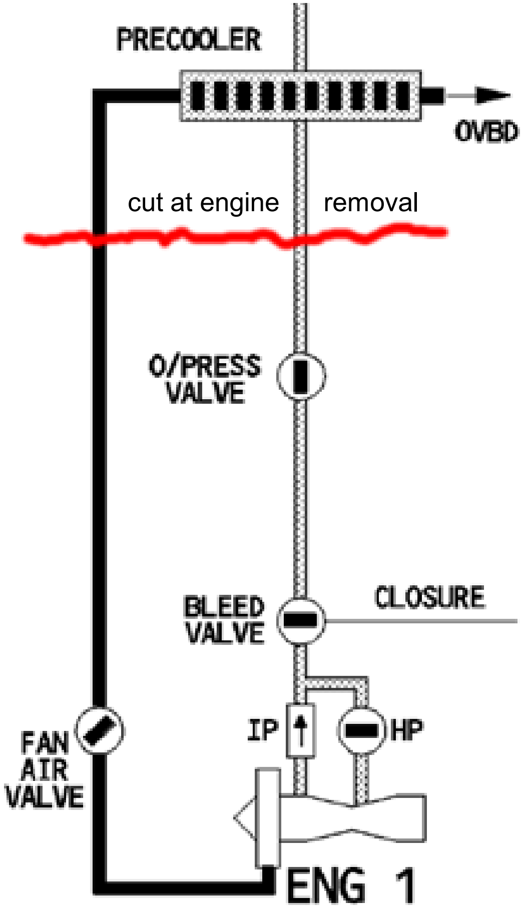
Top: 2010-09-17, US Airways US-432, Boeing 757-200. Bottom: 2018-12-10, Indigo flight 6E-237, Airbus A320neo.

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.

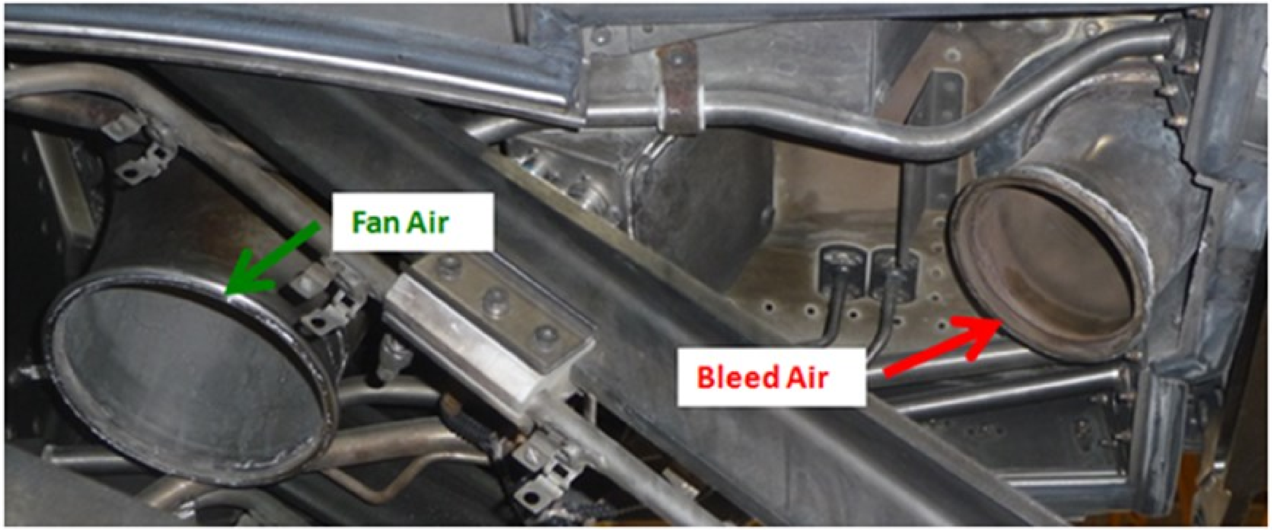
Picture source:
Video: https://youtu.be/dlPOeudTTCI.
The video explained:
https://purl.org/CabinAir/WaterContamination.

Engine Oil Colors Bleed Air Duct Brown



Airbus A320 FCOM

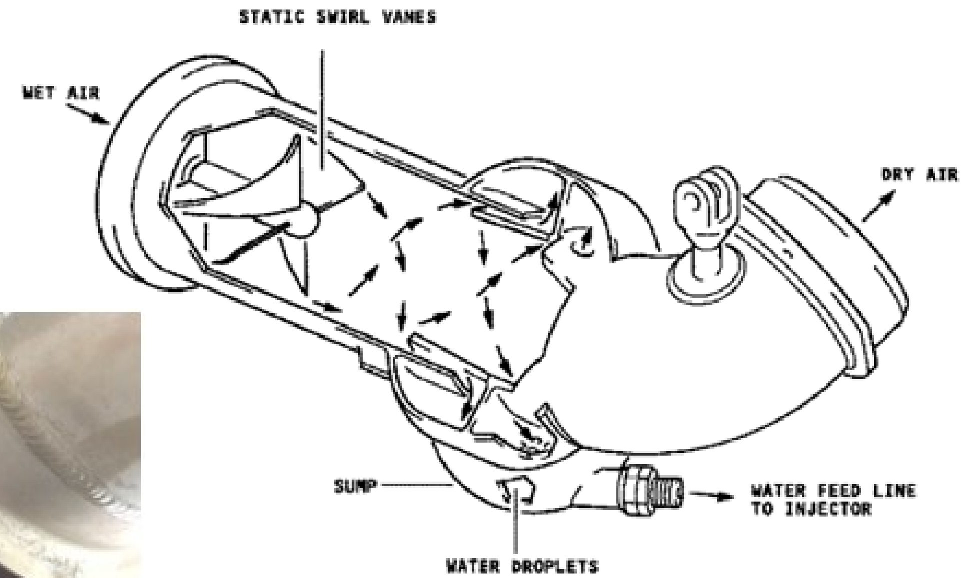
Fan air and bleed air ducts at the interface between engine and wing on an Airbus A320. The brown stain in the bleed air duct appears to be engine oil residue. In comparison, the fan air duct is clean. Air temperature in the bleed air duct about 400 °C.

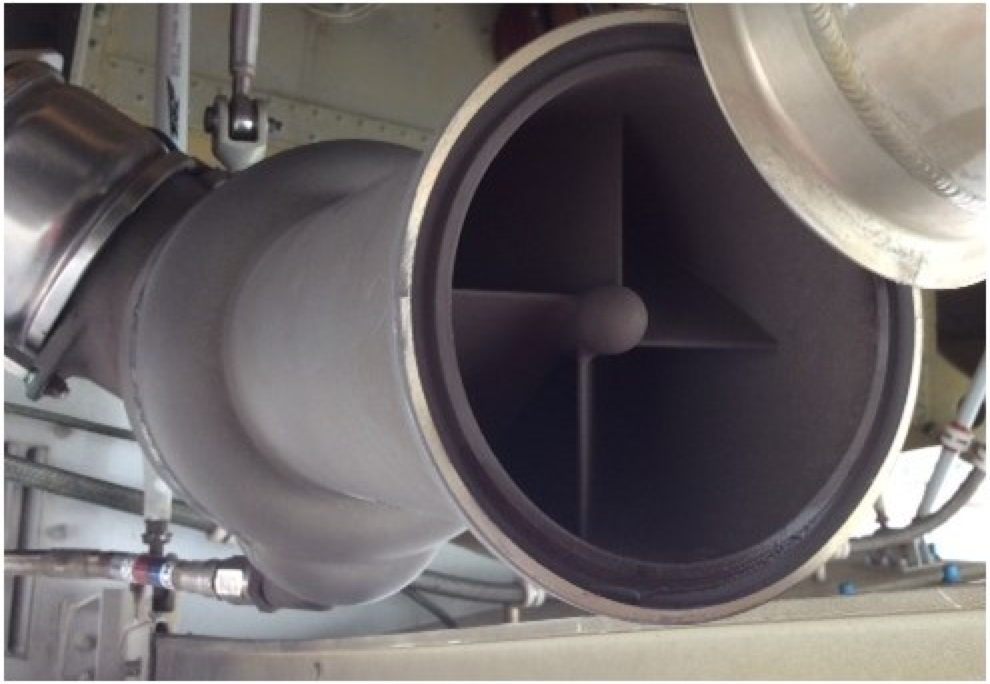


Engine Oil Colors Bleed Air Duct Black

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





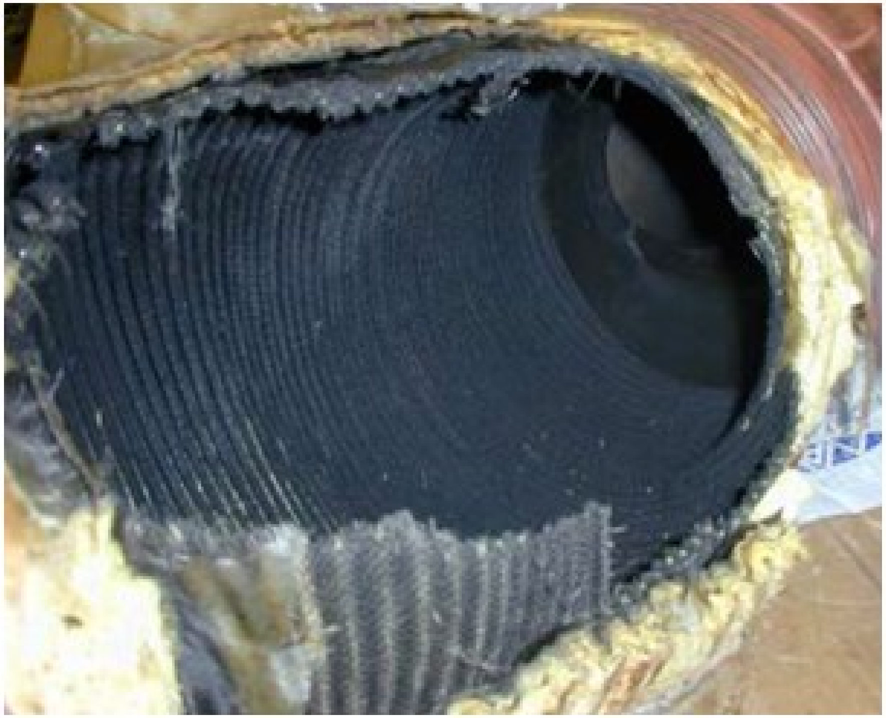
The Airbus A320 water extractor (Airbus 1999), is a part of the air conditioning pack. The inlet of the water extractor is covered with black oily residue.

Distribution of Engine Oil

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.

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

Flow Limiter in Air Conditioning Ducts

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

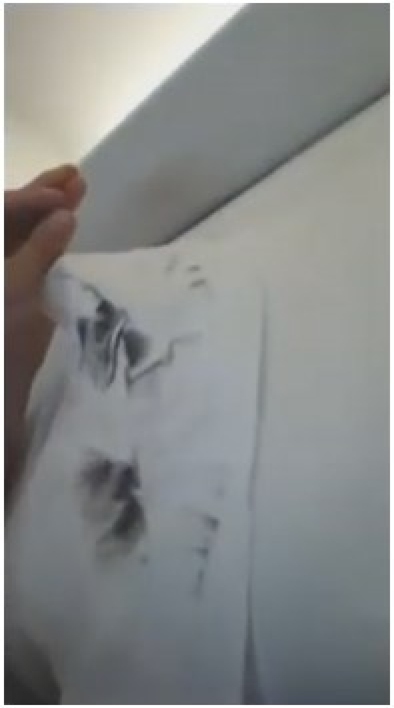
Engine Oil Colors Riser Ducts Black

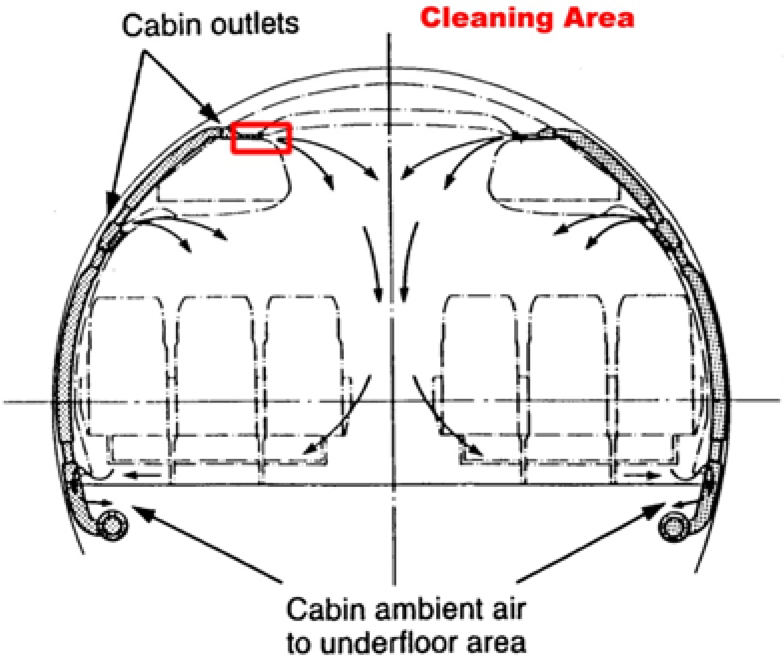
Video:
https://bit.ly/2YXcL3a

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

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).

Smoke Warning from Cargo Compartment, but No Fault Found (NFF)

https://purl.org/aero/PR2023-07-06

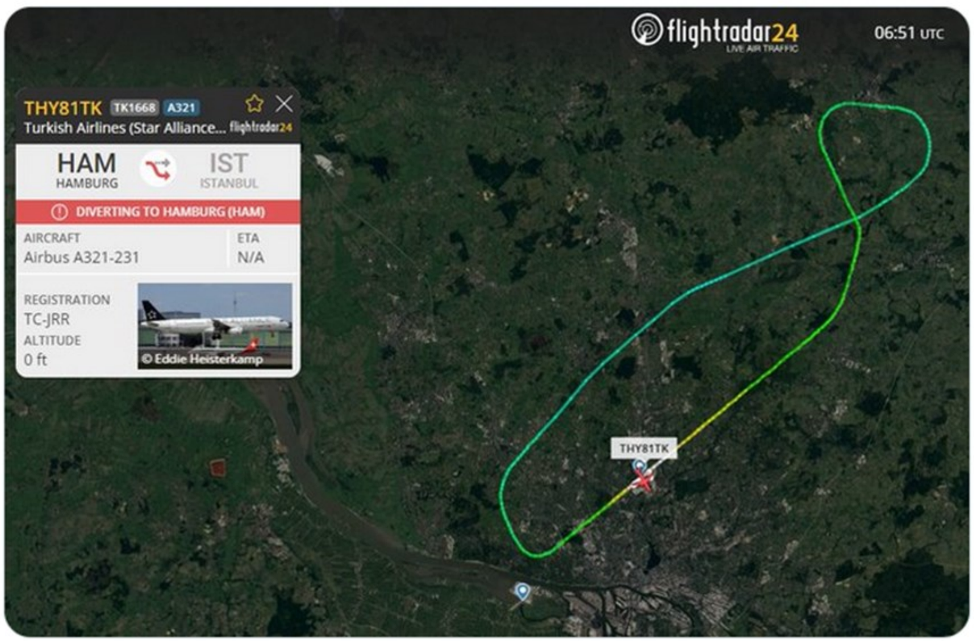
https://www.fzt.haw-hamburg.de/pers/Scholz/Aero/AERO_PR_A321-Kabinenluftkontamination/AERO_PR_A321-Kabinenluftkontamination_23-07-06.html

Cabin Air Contamination, but No Fault Found (NFF)

6 July 2023, Flight TK1668: Air Turnback of an Airbus A321 to Hamburg (HAM)

Turkish Airlines Airbus A321 (TC-JRR built 2011) safely returned to land at Hamburg Intl Airport (EDDH), Germany about 20 min after take-off from runway 23. Allegedly the pilots of flight #TK1668 to Istanbul received a smoke/fire warning in the cargo hold.

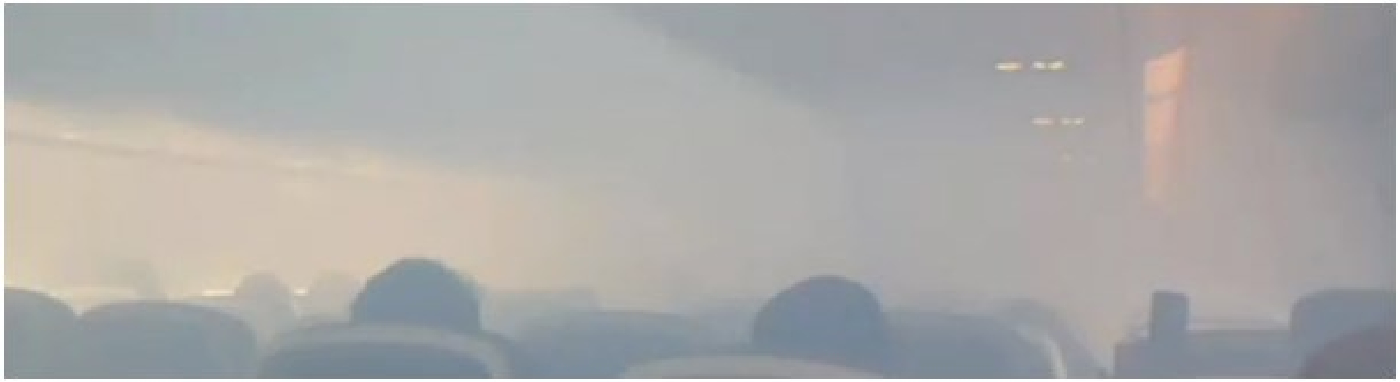
Post übersetzen



8:58 vorm. · 6. Juli 2023 · **6.204** Mal angezeigt

Other Examples:

Cabin Air Contamination Event Due to Engine Oil After Technical Fault

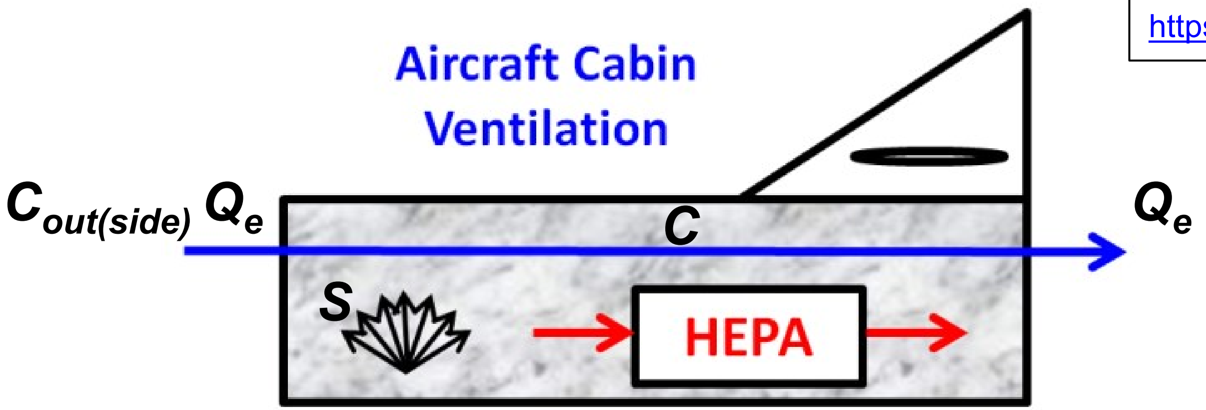


Top:2019-08-22, Hawaiian Airlines HA47, A321neo. Bottom: 2019-08-05, British Airways BA-422, Airbus A321.

Cabin Air Contamination, but No Fault Found (NFF)

Ventilation Equation

SCHOLZ, Dieter, 2020.
Aircraft Cabin Ventilation Theory,
Memo.
Hamburg University of Applied Sciences.
https://doi.org/10.31224/osf.io/ac6p8



$$S + Q_e C_{out} - Q_e C = V \frac{dC}{dt}$$

S: source strength in kg/s

Q_e: effective air flow rate for ventilation in m³/s

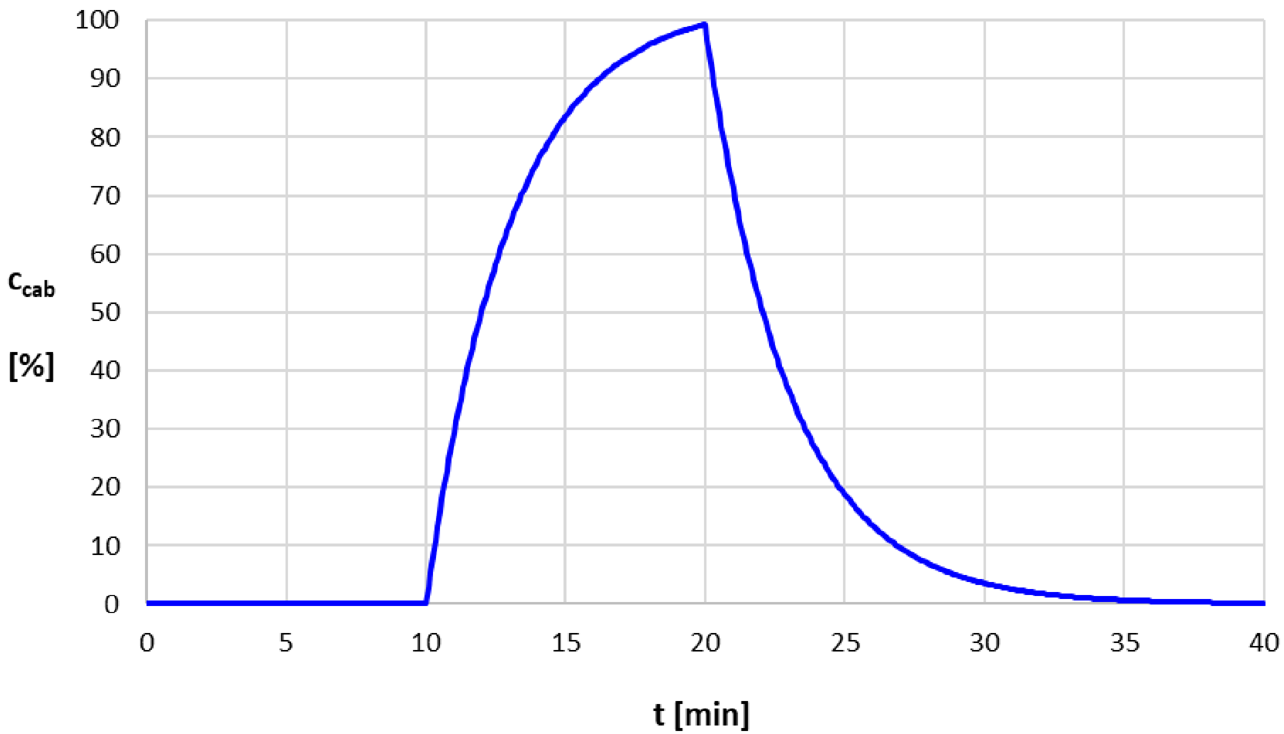
C: concentration of CO_2 or any other substance in kg/m³ in the room

C_{out}: concentration of CO_2 or any other substance in kg/m³ outside of the room

V: volume of the room

Cabin Air Contamination, but No Fault Found (NFF)

Cabin Air Contamination – Time History



Assumed concentration of a contaminant (e.g. engine oil) in cabin air. Strong contamination could be present as visible smoke. The concentration increases over 10 minutes with constant source strength of the contaminant. After this, it is assumed that no contaminant enters the cabin anymore. Cabin ventilation washes the contaminant out. After another 10 to 15 minutes hardly any contamination is left in the cabin air.

Cabin Air Contamination, but No Fault Found (NFF)

Cabin Air Contamination – Airbus A321

Instead of the A321-231, TC-JRR, here is a picture of the largely identical A321-231,TC-JRL from Turkish Airlines / Star Alliance in Düsseldorf (Photo: Marvin Mutz, CC BY-SA, Link)

Cabin Air Contamination, but No Fault Found (NFF)

Aircraft Rescue and Firefighting (ARFF) – Within Less than 20 Minutes the Airport Is Well Prepared to Meet a Landing Aircraft with Possible In-Flight Fire

The Airbus A321 was met by dozens of rescue vehicles, when on 6 July 2023 flight TK1668 returned to Hamburg (HAM) due to a smoke warning from the cargo compartment. No fault was found (NFF).

Picture source: Courtesy of and © by Blaulicht-News.de.

- **The problem is a fundamentally wrong design principle applied for the environmental control system (ECS) of all present passenger aircraft (except for the Boeing 787).**
- **It is wrong to use (unfiltered) compressed air from the engine (so called bleed air).**
- **Instead outside air must be compressed in dedicated compressors using air from a separate inlet.**

Contact

info@ProfScholz.de

http://www.ProfScholz.de

http://CabinAir.ProfScholz.de

Quote this document:
SCHOLZ, Dieter, 2025. Fire Protection in Aviation. In: *Tagung und Fortbildung Brandschutz* (Rilano, Hamburg-Finkenwerder, Germany, 06./07. März 2025).
Available from: https://doi.org/10.48441/4427.2348

Tagung und Fortbildung Brandschutz
Meding-Brandschutz, Bad Salzuflen, Germany
https://meding-brandschutz.de

Tagung und Fortbildung Brandschutz, 06./07. März 2025
https://web.archive.org/web/20250308164853/https://meding-brandschutz.de/Schulungen/Fordbildung-fuer-Brandschutzbeauftragte/

Elaya Hotel Hamburg Finkenwerder, **Rilano** Group GmbH
https://www.elaya-hotels.com/hamburg-finkenwerder

See also:
SCHOLZ, Dieter, 2018. Technical Solutions to the Problem of Contaminated Cabin Air.
In: *German Aerospace Congress* (Friedrichshafen, Germany, 04 – 06 September 2018). Presentation No. 0270.
Available from: https://doi.org/10.5281/zenodo.4072745