



ASHRAE Guideline 48P

Public Review Draft

Guideline 48P, Operational Best Practices for Air Quality within Commercial Aircraft

**First Public Review (October 2026)
(Complete Draft for Full Review)**

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(This foreword is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.)

FOREWORD

This guideline is intended to serve as a companion to ANSI/ASHRAE Standard 161-2023, Air Quality within Commercial Aircraft. Standard 161 provides an air quality standard that addresses the unique characteristics of the aircraft cabin design and operations. ASHRAE Guideline 28-2021, Air Quality within Commercial Aircraft is another companion document, compiling research and other supporting information related to Standard 161. This Guideline provides a collection of best practices which may be used by air carriers to meet or exceed the requirements of Standard 161.

1. PURPOSE

This guideline serves as a companion to ANSI/ASHRAE Standard 161 by describing operational best practices to assist aircraft operators to meet or exceed Standard 161 requirements.

2. SCOPE

- 2.1** This guideline applies to the occupied portions of passenger aircraft with a seating capacity of 20 or more passengers during ground and flight operations and to the occupied portions of cargo aircraft with a maximum allowable gross takeoff weight greater than 19,000 lb (8,600 kg) during ground and flight operations.
- 2.2** This guideline considers control of air contaminants, infectious aerosols, thermal conditions, and related factors such as humidity and pressure.

3. DEFINITIONS AND ACRONYMS

3.1 DEFINITIONS

air, ambient: the outside air surrounding the aircraft.

air, engine bleed: air extracted from the compressor stages of gas turbine propulsion engines and auxiliary power units. Also referred to as “bleed air”.

air, outside: the fraction of supply air that has not been recirculated in the cabin. As used in this guideline, the term usually refers to ambient air that is compressed in either the aircraft engines or APU, conditioned in the ECS, and supplied to the aircraft cabin. During ground operations, this term can also refer to ambient air that is conditioned by the ECS, ground cart, or airport conditioner, and delivered to the cabin.

air, recirculated: air from the aircraft passenger cabin that is reused as part of the supply air.

air, supply: air delivered to the aircraft cabin and used for pressurization, ventilation, temperature control, and humidity control.

air-conditioning system (packs): a part of the environmental control system, typically pneumatically powered, that provides cooling and heating for aircraft cabin temperature control.

aircraft, commercial: aircraft engaged in common carriage per FAA 8300.10 (FAA, 1986).

airstart: The process of starting an aircraft main propulsion engine using high pressure pneumatic power from a ground-based unit. Typically used when an aircraft's APU is inoperative or unavailable. The term "airstart" may also refer to the GSE unit providing the air.

auxiliary power unit (APU): a gas-turbine powered unit that provides electrical power and compressed air to operate aircraft systems independent of the aircraft propulsion engines.

bleed source: the specific pneumatic air supply providing bleed air to the aircraft environmental control system, including an engine, auxiliary power unit, or ground-based pneumatic source.

cabin: a term applied to any spaces in the aircraft occupied by passengers or crew members.

contaminant: an airborne constituent that may reduce acceptability of the air.

contamination event: an occurrence in which airborne contaminants are introduced into the aircraft cabin, flight deck, or ventilation system at concentrations sufficient to produce detectable odors, visible smoke, measurable pollutants, or a reportable air quality concern.

cockpit: see *flight deck*.

decontamination: the process of removing, reducing, neutralizing, or isolating contaminants from the aircraft environmental control system to restore acceptable operating conditions and air quality.

disinsection: a procedure intended to eliminate, control, or prevent the transport of insects on an aircraft through chemical, mechanical, thermal, or other approved methods.

dry motoring: rotation of a gas turbine engine using the starter system without fuel introduction or ignition.

environmental control system (ECS): the equipment in an aircraft used to pressurize, ventilate, air condition, dehumidify, or humidify the aircraft cabin. It includes cabin-supply airflow control, pressure control, temperature control, distribution, recirculation, and air cleaning.

flight: a term used in this guideline to describe the status of the aircraft anytime it is not in contact with the ground. (This definition is not necessarily consistent with the Federal Aviation Administration's definition of "flight operations.")

flight crew: pilots

flight deck: the portion of the aircraft occupied by the pilots for the purpose of aircraft operation (also referred to as the *cockpit*).

fume event: a contamination event involving the introduction of airborne contaminants into occupied areas of the aircraft that results in smoke, haze, odors, fumes, or reported adverse physiological effects.

ground operations: a term used in this guideline to describe the status of the aircraft anytime it is in contact with the ground and is occupied by at least one crew member.

ground personnel: ground-based (not flight crew) airline or contracted worker responsible for aircraft servicing and/or passenger-related functions such as customer service and boarding.

high-efficiency particulate air (HEPA) filter: a filter meeting the efficiency requirements specified in Standard 161 for removal of airborne particulate matter from recirculated air.

occupied: the state of the flight deck and cabin when one or more crewmember, passenger, or ground-based workers are present.

ozone converter: a part of the environmental control system or air-conditioning system used to reduce the ozone present in the outside air supply to acceptable levels for cabin occupant respiration.

pack burn: a maintenance decontamination procedure that operates portions of the environmental control system at elevated temperatures for a specified duration to remove or reduce contaminant residues through thermal decomposition, oxidation, volatilization, or a combination thereof.

personal airflow outlet (PAO): an adjustable air supply nozzle located at the passenger-seat overhead console or crew station that is individually controlled by the passenger or crew member. It is also commonly known as a “gasper” or an “individual outlet.”

pre-conditioned air system (PCA): a ground-based system that provides low-pressure ventilation air, which can be heated or cooled, to the aircraft cabin and flight deck which bypasses the APU and the air conditioning packs. PCA may refer to central systems (integrated into the airport building), point of use systems, and/or mobile units.

smoke event: an occurrence in which visible airborne combustion products, or airborne products that resemble combustion products, are present within the aircraft cabin, flight deck, cargo compartment, or ventilation system.

supplemental oxygen: oxygen supplied to the passengers and crew to prevent hypoxia.

thermal runaway: a self-accelerating condition within a battery cell or battery assembly in which heat generated by internal chemical reactions causes a rapid temperature increase that may result in fire, smoke, venting of gases, explosion, or propagation to adjacent cells.

ultrafine particle (UFP): an airborne particle with an aerodynamic diameter less than 100 nanometers (0.1 micrometers).

ventilation: the process of supplying air to or removing it from a space for the purpose of controlling air contaminant levels, cabin pressure, humidity, airflow patterns, and temperature within the space.

volatile organic compound (VOC): an organic chemical that readily evaporates into the air under normal environmental conditions and may contribute to odors, occupant exposure, or secondary chemical reactions.

3.2 ACRONYMS

Acronym	Acronym meaning
APU	Auxiliary Power Unit
CFR	Code of Federal Regulations
ECS	Environmental Control System
EASA	European Union Aviation Safety Agency
EPA	Environmental Protection Agency
ETF	Epidemic Task Force (ASHRAE)
FAA	Federal Aviation Administration
GSE	Ground Support Equipment
HEPA	High Efficiency Particulate Air
HP	High Pressure
ICAO	International Civil Aviation Organization
IFE	In Flight Entertainment
MEL	Minimum Equipment List
PAO	Personal Airflow Outlet
PCA	Pre-Conditioned Air
PED	Personal Electronic Device
PPE	Personal Protective Equipment
QRH	Quick Reference Handbook
SAF	Sustainable Aviation Fuel
UFP	Ultrafine Particle
UV	Ultraviolet
VOC	Volatile Organic Compound
WHO	World Health Organization

4. CABIN TEMPERATURE

The operational conditions and best practice recommendations described below are intended to assist operators to meet and maintain the cabin temperature requirements in ANSI/ASHRAE Standard 161, Table 5-1. Policies to meet the temperature requirements of Standard 161 should be established. During ground operations, additional capacity for cooling and heating may be necessary to effectively manage heat loads that are less predictable and more variable than those which occur in-flight. Also, the use of Personal Air Outlets (PAOs) in cabin crew work areas can be helpful to accommodate the increased activity level of the cabin crew throughout the flight by providing some control over the crew's thermal environment which can include radiant heat sources, such as ovens.

4.1 Define and Enforce a Boarding Policy for Hot and Cold Cabins

4.1.1 Background:

When the outdoor conditions are either hot or cold, it is important that ground personnel coordinate with the crew members and/or maintenance workers prior to commencing boarding to assess if the aircraft is in a suitable thermal state. Maintenance workers, crew members, and other responsible stakeholders should collaborate on the decision to board after all parties have walked the length of the aircraft cabin and have discussed any abnormal conditions that could prolong exposure to uncomfortable temperatures. Possible abnormal conditions include ground delays, ramp delays, inoperative ground or aircraft equipment, or an inoperative APU that necessitates an airstart. If the aircraft conditions are deemed unsuitable for boarding, then flight crew and maintenance should establish the underlying cause(s) for the conditions being unacceptable and determine if any action can be taken to rectify the situation, as well as the time required to do so.

The temperature limits in Standard 161 do not include any adjustment for relative humidity in the cabin. In-flight, the relative humidity of cabin air is normally low and not a factor. During boarding and deplaning, though, the relative humidity of cabin air can vary which can impact the suitability of the cabin thermal environment. Some airlines define a specific dry bulb temperature above which cabin crew are instructed to either not begin boarding or to suspend boarding. An 85°F/29°C cabin with 80% humidity will feel much hotter than an 85°F/29°C cabin with 10% relative humidity.

4.1.2 Best Practices:

- a. Establish minimum and maximum target limits during ground operations for pre-boarding and post-boarding phases, both for hot and cold ambient conditions. All temperature limits are consistent with the values in Table 5-1 of Standard 161. In hot conditions, the cabin temperature should not exceed 75°F pre-boarding and 80°F post-boarding. In cold conditions, the cabin temperature should not be less than 65°F to begin boarding. Maintaining these limits will require onboard temperature sensors in representative locations and crew/ground personnel procedures and training.¹

¹ Note: The 85°F (29.4°C) limit in Standard 161 which applies when IFE are operating is too high as a best practice, especially during boarding due to the elevated activity levels of passengers and cabin crew, elevated humidity within the cabin, and additional occupants (heat sources) entering the cabin which would further increase the cabin temperature.

- b. If the 80°F (26.7°C) limit cited in Standard 161 cannot be maintained during boarding or deplaning, then inflight entertainment (IFE) and other heat sources in the cabin should be turned off, to the extent feasible.
- c. An alternative approach to setting minimum and maximum temperature limits is for an operator to develop and implement a procedure prior to boarding passengers in which the ground personnel explicitly ask the lead cabin crewmember, either “Is the cabin temperature safe to board?” or “Is the cabin too hot/too cold?” This exchange can also be effective over a text/chat interface between the lead cabin crewmember and responsible ground personnel. Flight crew and other ground personnel should be included in this conversation, as appropriate.
- d. For locations/seasons/times of day when relative humidity in the cabin is anticipated to be above 50%, the upper cabin temperature limit in paragraph 4.1(a) should be adjusted downward for boarding policies. The upper limit should be decreased by approximately 1.0°F (0.56°C) for each 10% increase in expected relative humidity in the cabin above 50%.
- e. If a decision is made to commence boarding when the cabin is deemed too hot or too cold, the flight crew and cabin crew should follow airline procedures to file an internal report to describe the onboard conditions and necessary actions. The airline should monitor incoming reports and take corrective action.
- f. Review cabin temperature related reporting forms, operational data, and other data regularly to evaluate systemic underlying problems that resulted in boarding with unacceptable conditions and take actions to address any systemic underlying problems. Ensure that all responsible stakeholders are included. (See also Sections 4.2 and 4.3.)

4.2 Worker Training and Communication

4.2.1 Background:

A prompt and successful response to a too hot/too cold cabin scenario includes communication and coordination between flight crew, cabin crew, ground personnel, and maintenance technicians. On the aircraft, Crew Resource Management plays an important role in countering the effects of hot cabins. The temperature may be significantly different between the flight deck and the passenger cabin such that either the flight crew or cabin crew may be unaware of an issue. In some cases, the issue can be resolved by adjusting the aircraft Environmental Control System (ECS). Other actions include adjusting or changing a ground air supply source or suspending boarding, or maintenance response to a pilot logbook entry. Ensure clear communication and shared understanding of the relevant cabin policies and procedures.

4.2.2 Best Practices:

- a. Establish operational policies and provide initial and recurrent training for pilots, cabin crew, ground personnel, and maintenance technicians for how to respond to unacceptable temperatures.

4.3 Policies and Procedures for Sufficient Ground Air Supply

4.3.1 Background:

During ground operations, options for ventilation air are ground-supplied pre-conditioned air (PCA), ground-supplied high pressure (HP) air, APU bleed air, and engine bleed air. Operational conditions can affect the preferred source of air supply. For example, if a PCA unit is insufficient to cool the cabin during hot ambient temperatures, then HP air or APU bleed may be used. Operators need suitable options to handle predictable seasonal loads and to ensure backup air supply systems for unforeseen circumstances, such as extreme weather or equipment failures. Depending on the location, ground air supply equipment can be under the control of the airline, the airport authority, or some combination of the two.

4.3.2 Best Practices:

- a. Establish and enforce operational policies and procedures to ensure sufficient flow and suitable temperature of ground air supply to the aircraft at all locations.
- b. Develop a partnership (which may include written policies or legal contracts) with the airport authority, as needed, to ensure a sufficient supply of operational ground equipment at all stations.
- c. Evaluate the cooling capacity of each PCA unit at each location to ensure that it can meet the demands of the climate and the aircraft type which it services. If PCA units are undersized, establish a plan to phase out and replace units as quickly as feasible.
- d. Ensure that ground personnel at each location are trained to understand each airline's operational needs and procedures for cabin cooling and heating.
- e. For aircraft that do not rely on the APU for ground air, ensure that ground personnel are trained to prioritize air supply at the gate, as needed and as soon as possible after propulsion engine shutdown, to minimize the duration of no air supply to the cabin.
- f. Even with an optimally performing PCA system, certain operational issues may severely restrict the cooling capacity of the unit, primarily sharp bends in the air delivery hose, system leakage, or operation of the system in the incorrect setting. Ground personnel should be instructed and trained to avoid these issues, and PCA systems should be selected/installed which mitigate these potential human factors issues.
- g. Establish procedures to routinely test ground air supply equipment to ensure they are fully functional and suitably sized to manage anticipated cooling and heating loads within the range of anticipated relative humidity in operation. At a minimum, routine testing of PCA systems should include airflow, static pressure, and temperature at the aircraft connector. Remove equipment from service if it is not functioning properly so that it can be repaired.

4.4 Ensure Availability of Serviceable PCA Equipment at Every Aircraft Parking Position

4.4.1 Background:

An available and optimally performing PCA supply is important to maintaining a comfortable cabin temperature on the ground. At some locations, PCA systems are owned and maintained by the operators, while at others, they are under the control of a contractor working for the airport authority. If a PCA is not connected to the aircraft, then excessive cabin temperatures can result. Reasons include an insufficient supply of serviceable units, failure to prioritize PCA hook-up on arrival, and insufficiently sized or maintained units.

4.4.2 Best Practices:

- a. Ensure a sufficient supply of serviceable PCA units at each station with equipment that is routinely maintained and is designed to handle the heat, and humidity loads at that location. Coordinate and communicate with airport authorities, where relevant. This may require contractual obligations between the airline and the airport authority.
- b. Ensure that PCA units are adequately sized for the aircraft type serviced, as well as the climate of the location during all seasons. In particular, ensure that equipment is adequately sized for the anticipated wet bulb temperatures under high humidity conditions, in addition to the range of operational dry bulb temperatures. Also, note that certain aircraft types have operational limits for airflow, static pressure, and/or temperature at the PCA connection.
- c. Test PCA units at least twice per year to ensure optimal performance (within the aircraft limitations) at the end of the flexible hose, where the aircraft connection is made. Testing should include airflow, static pressure, and temperature measurements to ensure that the unit is performing per specification. The PCA hose should be inspected regularly for deterioration and debris and replaced as required. The PCA hose length should be adjusted to ensure that the connection can be made to the aircraft without sharp bends, which can severely limit the airflow to the aircraft cabin.
- d. If an aircraft is parked on the ground and becomes heat-soaked, establish operational procedures to pre-cool the aircraft before it is made available to the operation. If a serviceable PCA supply is not available to an aircraft, an alternate air supply (HP air, APU bleed, or engine bleed) should be used.

4.5 Establish an Aircraft Maintenance Program to Ensure ECS Efficiency and System Performance

4.5.1 Background:

Environmental Control Systems (ECS) are typically designed with a certain tolerance for cooling and heating efficiency, and the standard maintenance programs are suitable when operating ECS under ideal conditions. Additional maintenance may be necessary to ensure sufficient heating and cooling under non-ideal conditions, especially if aircraft are routed to locations with predictably high (or low) ambient temperatures. The air distribution system ducting downstream of the ECS typically contains flow restrictors. These restrictors can become clogged with dust/debris which can limit the airflow to the cabin. In addition, airflow can be reduced by leaks or other blockages in the system. Small leaks in the ECS may affect the cooling performance without activating the leak detection system. Other ECS components (e.g., Air Cycle Machine, heat exchangers) may degrade over time due to wear, blockage, contamination, or internal leakage. This can affect total system performance, especially as the system ages.

4.5.2 Best Practices:

- a. Review ECS maintenance program and procedures fleet-wide and consider supplementary tasks or procedures to ensure that the systems can function optimally to manage high heat loads. Specific ECS maintenance recommendations include:
 1. Regularly clean cabin temperature sensors. If the sensors are dirty, they may not report an accurate cabin temperature to the ECS.
 2. Regularly clean the ECS heat exchangers, reheaters, and condensers to improve performance.
 3. Periodically overhaul or refurbish certain ECS components affected by wear or internal leakage.
 4. Regularly perform leak checks of the ECS to ensure optimum performance. Ultrasonic imaging technology has been used to successfully detect small leaks in pressurized air systems.
 5. Establish a regular maintenance program to clean the restrictors and check the cabin air outlets for adequate airflow.

4.6 Establish Operational Restrictions for Inoperative APUs, Packs, and Bleed System Components

4.6.1 Background:

Aircraft may be dispatched with certain equipment inoperative as specified by a Minimum Equipment List (MEL). The MEL is a regulatory-approved document that specifies what equipment can be inoperative while still allowing the aircraft to operate under specific conditions safely and in compliance with regulations. When an aircraft is dispatched with an inoperative APU, pack, or other bleed system component, then special attention should be given to ensure adequate cabin cooling/heating and ventilation. In all cases, the inoperative system should be repaired as soon as possible to restore full ECS performance.

4.6.2 Best Practices:

- a. Minimize the duration that an APU, ECS, or bleed system component is inoperative and adjust operations (e.g., aircraft routing, maintenance schedules) as feasible to prioritize cabin comfort (airflow and temperature).
- b. Connecting the aircraft to a ground air source should be prioritized after the propulsion engines are shut down to minimize the time that the cabin is left with no airflow.
- c. If feasible, aircraft with an APU or ECS component on MEL should be routed to locations with adequate ground support facilities to ensure that cabin temperatures can be maintained (refer to Section 4.1(a)).

4.7 Address Radiant Cooling from Door Seals

4.7.1 Background:

Vertical and horizontal temperature differentials are created by radiant cooling from the surface of the seals around the cabin exit doors during a flight.

4.7.2 Best Practices:

- a. If supplemental door heaters are available then operate them, as needed, to ensure that the areas adjacent to cabin doors are within the acceptable range of operating temperatures. If supplemental door heaters are not available, adding extra insulation to the area may be an option.

4.8 On Propeller Aircraft, Avoid Operating a Main Engine Near an Open Cabin Door

4.8.1 Background:

When there is no ground air supply, operational procedures may allow operation of the left engine without the propeller to power the ECS. This procedure increases the risk of hot exhaust from the engine entering an open cabin door.

4.8.2 Best Practices:

- a. On propeller aircraft, avoid operating a main engine on the same side of the aircraft as an open cabin door.
- b. Ensure an adequate supply of serviceable PCA units at all locations.

4.9 Other Recommendations

4.9.1 Background:

Operational and maintenance practices independent of the heating, ventilation, and air conditioning systems can also impact cabin temperatures. For example, closed window shades and open PAOs can help reduce cabin cooling needs when the outside air temperature is high, especially during ground operations and the cooling capabilities of the aircraft are reduced. Also, the provision of ice enables cabin crew to drink cold water, serve cold water to passengers, and use it in a compress for injuries or for cooling.

4.9.2 Best Practices:

- a. Establish operational procedures to close window shades and open PAOs during hot weather operations. Establish cabin crew procedures to encourage passengers to do so.
- b. Routinely inspect and maintain window shades and PAOs, prioritizing any necessary repairs to limit the duration of an inoperative item.
- c. Ensure that ice is provisioned fleet-wide at all locations.

5. AIRBORNE CONTAMINANTS

5.1 Introduction

Various sources of airborne contaminants may be present in the aircraft cabin (Table 5-1). Some of these exposures can be anticipated during routine operations, while others are less frequent. In general, airborne contaminants can enter the cabin from the air supply system (ECS-supplied) or can be generated within the pressurized fuselage, including the cabin or flight deck (cabin-generated) (SAE, 2021). These operational best practice recommendations are intended to assist operators in controlling exposure to the ECS-supplied and cabin-generated airborne contaminants listed in Table 5.1 during normal and abnormal conditions. Each set of recommendations is presented in the following format: (1) Typical scenario; (2) Preventive best practices; and (3) Remedial best practices. The user is directed to Standard 161 and Guideline 28 for requirements and supplemental information.

Table 5.1: Sources of airborne contaminants that may be present in the cabin and flight deck

ECS-supplied (Section)	Cabin-sourced (Section)
Deicing Fluid (5.2)	Batteries (5.9)
Engine Oil and Hydraulic Fluid (5.3)	Cargo, Carry-On Bags/Belongings (5.10)
Engine Compressor Wash (5.4)	Dry Ice (5.11)
Exhaust Fumes (5.5)	Electrical Systems (5.12)
Fans (5.6)	Flame Retardants (5.13)
Fuel (5.7)	Galley (5.14)
Ozone (5.8)	Insecticides (5.15)
	Lavatory (5.16)

NOTE: The most effective way to mitigate an exposure is to control it by design (i.e., elimination, substitution, and engineering controls). Design requirements and recommendations are provided in Standard 161, but not in this operational best-practice guideline. In many cases, to implement the provisions in this guideline, it will be necessary to train relevant personnel, which may include the mechanics, ground staff, cabin crew, and pilots; see Circular 344-AN/202 (ICAO, 2015) for guidance. The need for training should be understood by the users of this guideline and will not always be specified.

NOTE: This information does not replace or supersede manufacturer or operator procedures. It is intended to provide supplemental best-practice recommendations. Before incorporating these recommendations, an operator would need to evaluate their applicability to its aircraft types and operation.

5.2 Deicing Fluid

5.2.1 Typical Scenario

Deicing fluid can be ingested into either the APU or the engine and passed through the ECS into the cabin and flight deck air. Deicing fluid ingestion typically occurs during or immediately following a deicing operation. Sometimes, the fluid can contaminate the air supply several flight cycles after a deicing operation if the viscous fluid becomes entrapped within the aircraft structure and is then ingested (e.g., due to drainage and changes in temperature or attitude) into either the APU or engine. In rare cases, deicing fluid may seep through exit door and window seals, and then into the cabin. There is some evidence that deicing fluid may act as a solvent and release oil residue from duct and pack surfaces (ASHRAE, 2022).

5.2.2 Preventive Best Practices

- a. Procedures for deicing staff should emphasize proper techniques to prevent or minimize deicing fluid entry into the cabin, as follows: (i) Do not spray deicing fluid into or near the engine or APU inlets during application; and (ii) Do not apply high-pressure sprays on or near entry door seals and flight deck window seals. Recurrent training for deicing staff should emphasize these procedures to prevent deicing fluid ingestion that results in air supply contamination.
- b. If applicable, flight crew procedures should include measures to reduce the likelihood of deicing fluid ingestion. These measures may include turning off the bleed air, air-conditioning packs, or ground conditioned air sources during a deicing operation. Once a deicing operation is finished, the engine or APU should be allowed to run for at least three minutes before the bleed air is switched on to allow purging of any residual deicing fluid from the engine, and to reduce the risk of deicing fluid contamination into the cabin air supply. Periodic reminders to flight crews prior to the deicing season may help to reinforce these measures.
- c. The aircraft maintenance program should include tasks to periodically inspect the doors and sliding flight deck windows and to maintain them to ensure that the seals are in good condition. The replacement schedule for door and window seals should meet or exceed manufacturer recommendations. If operator experience includes frequent deicing fluid leakage through door or window seals, more frequent inspection and/or a more stringent control measure—such as a detailed visual inspection in place of a general visual inspection—may be appropriate.
- d. Alternative deicing procedures and products (e.g., infrared deicing) may reduce the likelihood of contamination (FAA, 2020a).

5.2.3 Remedial Best Practices

- a. If the air supply system is contaminated with deicing fluid, then the fluid residues should be removed at normal ECS operating temperatures. This cleaning process may be accelerated by operating the ECS in the cooling mode and then the heating mode (i.e., all operating conditions) until the deicing fluid odor is eliminated. This procedure should be performed by maintenance staff without crew and passengers onboard.
- b. To prevent repeat deicing fluid ingestion events, special care should be taken to inspect the APU and engine inlet areas and surrounding structures, and to clean any excess fluid to prevent it from being ingested during subsequent flight operations.

5.3 Engine Oil and Hydraulic Fluid

5.3.1 Typical Scenario

As air travels through the ECS, and is eventually delivered to the cabin, it undergoes many changes (i.e., pressure, temperature, airflow, moisture content, etc.). It is helpful to understand the basics of engine oil and hydraulic fluid chemistry in this environment during a “typical” bleed air contamination event, routine changes in engine power and pressure settings, and during a decontamination procedure (e.g., pack burn).

Hydrolysis is thought to be the primary chemical process in the aircraft ECS by which turbine engine oil base stock is degraded by heat and moisture into carboxylic acids and other compounds over time. In addition to odorous carboxylic acids, ultrafine particles are also generated by condensation as volatile components of engine oil are cooled (FAA, 2024a).

engine oil + heat + moisture + time $\xrightarrow{\text{yields}}$ odorous carboxylic acids + other organic compounds
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Hydraulic fluid components produce far fewer ultrafine particles than oil but can still be degraded by heat and moisture.

Once oil or hydraulic fluid components enter the ECS, they can be deposited onto ECS surfaces and be entrained in the conditioned air supplied to the cabin and/or flight deck, depending on the bleed air source(s), pack settings, and system configuration.

System contamination with oil or hydraulic fluid can subsequently create secondary sources of contamination (e.g., ducting or ECS). The high surface area components of the ECS (e.g., ozone converters, heat exchangers) are especially susceptible to accumulation of contaminants. As an example, the APU could contaminate downstream ECS ducting with oil, and then contaminants could be released later, even when the APU is not operating (during descent, for example) with changing temperatures, pressures, humidity, and interactions between different contaminants (FAA, 2025a; ASHRAE, 2022). As a result, the source of fumes during a given flight may not be obvious.

Maintenance decontamination procedures remove some engine oil and hydraulic fluid residues from the ducting and ECS components (e.g., heat exchangers, condensers, reheaters, etc.) by increasing any combination of heat, moisture, and time; refer also to Section 5.3.3(c).

Some aircraft are equipped with either an ozone converter or a VOC/ozone converter upstream of the air conditioning packs. There are different commercial options, each with its own proprietary catalyst. Still, a reduction in some oil fume components, based on measurements upstream and

downstream of different units, has been shown, with the combined VOC/ozone converters appearing to be more effective than the ozone-only converters.²

Turbine engine oil, hydraulic fluid, and their associated thermal decomposition products can be introduced into aircraft bleed air either via (a) internal leakage or (b) external ingestion, as described below:

5.3.1.1 Internal Leakage

In the internal leakage scenario, engine oil is introduced directly into the compressor section of the engine or APU. Oil and its thermal decomposition products are then introduced into the engine bleed air stream which passes through the ECS and are supplied to the cabin and flight deck. Three possible scenarios are described below which may be the source of internal leakage:

- a. Seal wear or failure: A worn or failed seal forward of the engine or APU compressor section can result in oil leakage into the bleed air supply, which may be more likely to occur during transient engine power/bleed system configurations, such as APU/engine start, takeoff/climb, and descent.
- b. Low sealing-air pressure: Some engine seal designs use bleed air to create sealing pressure to prevent oil leakage. With this design, if the bleed pressure is too low (for example, during engine start or prolonged engine cranking), there may be insufficient sealing pressure, and oil may bypass the seals. Compressor wash procedures are especially susceptible to this condition (see Section 5.4). The specifics of a given engine/seal design will determine the precise bleed pressure needed to prevent oil leakage. For example, if the seal design requires relatively high bleed pressure, it may be susceptible to leakage during normal transient conditions (engine start, power changes). A more robust seal design may provide adequate sealing pressure during all operational conditions to prevent leakage (Rolls Royce, 2014).
- c. Overpressure of oil system: An overpressure condition of the engine oil system may cause oil to leak past the seals, even if the sealing air pressure is adequate. As an example, an overpressure condition may be caused by a blocked oil vent line. There are various mechanical causes for this, in addition to overservicing, all of which can drive excess oil across the seal.

NOTE: The scenarios described above may be possible at various locations within the engine. Internal leakage within the engine compressor section can result in bleed air contamination. Leakage within the turbine section will be introduced into the engine exhaust airstream, not the bleed air.

² Preliminary and limited data suggests that a VOC/Ozone converter can significantly reduce the high ultrafine particle counts in oil fumes in bleed air (Aeroparts, 2024) and odorous carboxylic acids and other VOCs (BASF, 2026; Aeroparts, 2024). These effects are more pronounced with a VOC/Ozone converter than for an ozone-only converter (Aeroparts, 2024). Other research findings are similar but were not consistently replicated across different platforms (FAA, 2025a; FAA, 2024a). Also, the results varied depending on if ozone was also present. Additional work would serve to validate and quantify these improvements.

5.3.1.2 External ingestion

In the external ingestion scenario, engine oil or hydraulic fluid can be ingested into the APU compressor via the APU inlet. The fluid could be from an external APU leak, or it could be from a different component on the aircraft. Sources of fluid that can be ingested into the APU inlet vary based on the specific aircraft design. For example, aircraft with an APU inlet situated low down on the fuselage are significantly more prone to external ingestion unless the design has been modified to mitigate the ingestion. External ingestion of oil or hydraulic fluid into a main propulsion engine is possible, but less common. Examples of ingestion include:

- a. Overservicing of APU oil can lead to spillage which can be reingested into the APU inlet.
- b. Oil or hydraulic fluid can leak past O-rings in the engine and then be ingested.
- c. Oil can leak past O-rings in the APU and then be ingested into the APU inlet.
- d. Oil that either accumulates behind the APU compartment door and seeps through the door seal or is released from the drain mast can be reingested into the APU inlet, depending on the proximity and position of the drain mast and inlet.
- e. Hydraulic fluid leakage from a flight control actuator can be ingested into an APU inlet.
- f. Hydraulic fluid leaks or spillage from other systems (e.g., landing gear) can drain to the surface of the belly of the aircraft and be entrained into the APU inlet, depending on its location.

5.3.2 Preventive best practices

- a. An important and effective best practice to avoid the ingestion of oils and/or hydraulic fluids is to maintain a clean engine, APU, APU compartment, and air inlet area.
 1. Any external fluid leaks, especially oil or hydraulic fluid, should be cleaned immediately to avoid being ingested into the APU/engine inlet. A clean aircraft exterior and APU/engine compartments also make it easier to identify current and future leaks.
 2. When servicing the engine or APU with oil, or servicing the hydraulic system, care should be taken to service to the proper levels in accordance with the manufacturer's procedures to avoid an overservicing condition. Immediately clean any spillage that occurs during the servicing procedure.
 3. Preventive routine inspections for oil or hydraulic fluid leakage, and prompt corrective actions, can prevent ingestion events.
 4. Many engines and APUs have a drain path for externally leaking fluids. Each drain path should allow for any leaking fluids to drain away from the air inlet and exit the aircraft. Routine inspections of each drain path for condition and function can help to ensure continued proper drainage of external leaks.
 5. Oil and hydraulic fluid can accumulate in areas upstream of an APU inlet (for example, in a structural cavity in the tail or the belly of the aircraft or within the acoustic lining material in the APU inlet duct). Routine inspections and cleaning of the areas upstream of the APU inlet can prevent future events.
- b. If available, bleed air filtration or air cleaner options should be installed and operated. An effective option removes particulate and volatile components of sources of bleed air contaminants over the range of operating conditions, without undesirable byproducts. Technologies include but are not limited to: (a) Catalysis (e.g., VOC/ozone converter),

- especially if the converter processes both APU and engine bleed air; (b) VOC adsorption technology; and (c) High-efficiency particulate filters.
- c. If available, bleed air contaminant monitoring (see Section 7.2, ASHRAE STD161) should be installed and operated. An effective monitoring system should supplement crewmembers' professional judgement of the onboard environment. It should be robust, reliable, and allow flight crew to promptly identify the issue and isolate a contaminant source in real time to mitigate ongoing exposure and to assist in maintenance troubleshooting.
 - d. Only use compatible seals, bearings, and oils designated by the applicable engine, APU, or aircraft system manufacturer. Inspect, maintain, and upgrade engine/APU seals according to the best practices specified by the manufacturer.
 - e. Use engine oils and hydraulic fluids with reduced quantities of hazardous components, where available.

5.3.3 Remedial best practices

Maintenance procedures to address an oil or hydraulic related bleed air contamination event should include these three steps (in order) and be in accordance with manufacturer and/or operator published procedures. Before any of these procedures (especially engine runs and pack burn/decontamination procedures), make sure that there are no non-essential personnel on the aircraft. Provide essential personnel (i.e., maintenance workers) with suitably protective PPE and procedures to avoid exposure to contaminants in the bleed air system during troubleshooting, decontamination, and associated system inspection/cleaning procedures. Maintenance task cards should also direct personnel to exit the aircraft if they experience any symptoms during these procedures and should include guidance to help personnel determine when it is safe to continue with the procedure.

a. Identify the source:

1. If an oil or hydraulic fluid contamination event is suspected, the first step should be to determine the bleed source from which the contamination originated (e.g., engine 1, engine 2, APU, or ground connection). A black light can be useful to distinguish between oil and hydraulic fluid. A bleed air monitoring system (see 5.3.2.c.) could assist maintenance staff by reliably locating the location/type of contamination. Maintenance review of onboard conditions described in the crew reports can also supplement troubleshooting actions.
2. Once the bleed source has been identified, detailed inspections should be done to pinpoint the location. This may require tracing a fluid leak path back to its origin or operating the engine or APU to try to reproduce the condition.
3. If internal leakage is suspected within an APU or engine, manufacturer recommended procedures typically include boroscope inspections for evidence of oil.
4. Unless fumes are reported during ground operations, it can be difficult to reproduce the fumes on the ground because the engine power settings, air conditioning system configuration, and temperature/pressure/humidity can be different. This makes it more difficult for maintenance staff to successfully identify and remedy the source. However, every attempt should be made to duplicate the flight conditions during the event. If the specific conditions are unknown, or if unable to reproduce the event, the engines and ECS should be operated over a range of conditions (high power/low power, high

temperature/low temperature) to provide the best chance of reproducing the event or to accomplish other precautionary maintenance or inspections to avoid a potential repeat event.

b. Address the source:

1. Once the root cause has been identified, any discrepancies must be corrected to eliminate the source of the oil or hydraulic fluid. Corrective action could include replacing an o-ring or seal, a line replaceable unit/component, or the engine/APU.
2. On its own, cleaning/decontamination is not a corrective action. Every effort must be taken to determine the primary source of the contamination. If the downstream system is cleaned without correcting the primary source, there is an increased likelihood of a repeat event. Unless another source has been identified, the APU should not be ruled out as a primary source even if it is not operating during the event.
3. Note that some fume events are not caused by a mechanical fault or failure. Examples include overservicing an oil reservoir (the excess can enter the bleed air) and dry motoring an engine (oil can cross a compressor seal). Also, the primary source of a previously reported fume event may have been addressed, but if residues remain on downstream surfaces (e.g., packs or ducting) they can be released under particular conditions on a subsequent flight (FAA, 2025a).

c. Clean/decontaminate downstream of the source:

1. Engine oil and hydraulic fluid contamination of bleed air can leave residues throughout the air conditioning system, including: (a) the pneumatic system ducting; (b) the ECS (air conditioning pack) components and high-pressure ducting; and (c) the low-pressure air distribution system ducting downstream of the mix manifold. If downstream surfaces are not properly cleaned, they can become a secondary source and generate repeat events.
2. Cleaning/decontamination procedures may include some combination of: (a) a high-temperature decontamination (sometimes referred to as “pack burn”) of the pneumatic system ducting and ECS components which heats the system to temperatures sufficient to remove some of the residual surface contamination; (b) manual cleaning processes; and (c) component replacement. Note that low pressure air distribution system ducting typically contains foam or fiberglass material which cannot be cleaned with a pack burn because of relatively low maximum temperatures in that part of the system. If contaminated, these components should be manually cleaned or replaced.
3. To avoid additional contamination of the distribution ducting downstream of the air-conditioning packs, the packs and the ducting upstream should be isolated from the rest of the system, and the high-temperature contaminated air should be vented overboard and not routed through the downstream ducting and delivered to occupied areas.
4. When evaluating the potential effectiveness of a “pack burn” procedure, the local temperature and pressure at each location should be considered. The different components of the ECS operate under very different conditions. For example, the temperatures at the heat exchangers may be sufficient to remove residual contamination, but some of the components on the “cold side” of the packs (for example: reheaters or condensers), may not get hot enough to remove the contamination and must be cleaned or replaced.

5. Maintenance procedures for cleaning/decontamination should include a verification procedure where the aircraft engine and ECS systems are operated under a variety of temperatures and pressures to attempt to duplicate an event. If fumes are detected during the verification procedure, more thorough decontamination is necessary.

5.3.4 Additional best practices:

- a. Most aviation turbine engine oils will fluoresce under an ultraviolet (“black”) light. Most hydraulic fluids will not fluoresce. A black light may be useful to either identify or rule out oil. A filtered UV-A (365 nm wavelength) light is recommended because it does not include visible (purple) light that interferes with leak detection, and it efficiently causes the oil to fluoresce, typically as a blue/cyan/purple color.
- b. Visual inspection (with or without a black light) of ducting and ECS components will only be useful for significant contamination. Lower levels of residual contaminants may have accumulated internally on some components (e.g., internal surfaces of an ozone converter or internal heat exchanger fins), such that they are not visible but can still contribute to a repeat event.
- c. Every effort should be made to minimize maintenance worker exposure to fumes generated during the isolation, troubleshooting, and decontamination procedures.
- d. Maintenance troubleshooting for suspected oil or hydraulic fluid contamination should not be done with crew or passengers onboard the aircraft.
- e. Onboard automated sensors are the preferred tool to identify the presence of airborne contaminants. If workers must rely on their sense of smell, then remember that they can quickly be desensitized to a persistent odor. These options may be helpful:
 1. Wear a respirator and quickly remove it to smell the air to determine if an odor is present.
 2. Leave the aircraft for several minutes then return to determine if an odor is present.
 3. Ask another maintenance worker who has not been on the aircraft to smell the air to determine if an odor is present.
- f. Ground Support Equipment (GSE), such as HP pneumatic sources or pre-conditioned air, can also introduce oil or hydraulic fluid into the aircraft air supply systems, either through an internal leak in the GSE, or ingestion into the air inlet. GSE for ventilation supply air should be inspected and serviced, according to each manufacturer’s recommendations. If GSE is a suspected source of onboard fumes, remove it from service immediately and check for evidence of oil or fluid leaks in the unit. GSE can also be a source of exhaust fumes that may be entrained into the bleed air (see Section 5.5).

5.4 Engine compressor wash

5.4.1 Typical scenario

Engine compressors are periodically washed to maintain performance and fuel efficiency. There can be a correlation between a compressor wash and fumes in the bleed air, especially on the first flight after the engine is washed, and especially during engine start and takeoff/climb when the engine is operated at maximum thrust. An engine compressor wash typically involves spraying water – sometimes mixed with cleaning solution – into the compressor while either “dry motoring” (rotating the engine using its starter motor, without fuel or ignition) or manually cranking the

engine at low speed, all so that the blades, casing, vanes, and other components can be washed. While rotating at a low speed, the engine generates oil and air pressure. However, the pressure may not be high enough to ensure proper operation of oil seals. Depending on the engine and the wash procedures, oil can leak into the engine compressor section where it may enter the bleed air system. Engine compressor wash procedures should include steps to ensure oil and other contaminants are not ingested into the bleed air system. Bleed-sourced fumes reported after an engine compressor wash can contain oil, water, cleaning solution, and/or debris from the compressor blades.

5.4.2 Preventive best practices

- a. Engine and APU compressor wash procedures should include precautions to ensure oil and other contaminants do not enter the bleed air system. The wash procedure should be accomplished with the bleed air system off or disconnected and should include rinse and/or post-wash testing to remove any residual contamination from the engine compressor section and bleed ducting to prevent fumes from entering the cabin when the aircraft resumes revenue flight operation. The specific procedure may vary depending on the aircraft and engine/APU model. Some operators have had success with a procedure that involves operating the engines and bleed system with the packs off and discharging the air through the HP Ground Connection (a special tool may be required to hold open the HP Ground Connection Check Valve). Five to 15 minutes of engine run time should be sufficient to remove most, if not all, of any residual contamination. Operator experience may be used as supporting data to shorten or lengthen the duration of the engine run.
- b. Require the maintenance logbook entry to be written in plain language that one or more engines were washed. Add language to the Flight Operations Manual that if fumes are reported on the flight immediately after an engine wash, then oil and wash water are the likely source.
- c. Operators should monitor aircraft after engine compressor washes and if an association between engine washes and fume events is noted, then the adequacy of the engine wash procedures and compliance with the written procedures should both be reviewed and modified as necessary to ensure a clean system.

5.4.3 Remedial best practices

- a. Engine-sourced fumes reported during the initial phases of the first flight after a compressor wash are likely some combination of oil, water, cleaning solution, and/or debris from the wash process that contaminated the ECS. Decontamination of the ECS should be sufficient to remove any residual contamination in the system (Refer to Section 5.3.3.c)

5.5 Exhaust fumes

5.5.1 Typical scenario

Exhaust fumes are most likely to be ingested into the cabin air supply system during ground operations (i.e., gate time, taxi in and out), especially when positioned near other aircraft. The airport environment is, to varying degrees, polluted with exhaust fumes sourced to aircraft engines

(including APUs), GSE, and other vehicles. Exhaust fumes contain elevated concentrations of carbon dioxide, carbon monoxide, UFPs, and nitrous oxides. The UFPs in aircraft engine exhaust are dominated by engine oil base stocks, plus oil additives (Ungeheuer et al., 2021; Fushimi et al., 2019), with levels that may vary depending on engine power level, engine maintenance, and age. Pollutants in ambient air are external to the aircraft but, during ground operations, ambient airport air can be drawn into the cabin for ventilation without being filtered. Various factors influence the degree to which exhaust fumes are ingested into the cabin air supply, including the source of supply air during ground operations (i.e., engines, APU, PCA, start-cart) and prevailing wind direction. In some scenarios, an aircraft may ingest its own exhaust fumes (for example if propulsion engine exhaust is ingested into the APU). Since 2004, VOC/ozone converters have been an option on certain aircraft to target VOCs generated by aircraft engine exhaust and related odors (Nurcombe, 2005). The catalysts have changed over time, and suppliers claim that they are now more efficient at removing VOCs via oxidation. High UFP count (ASHRAE, 2022; Fushimi, 2019) and high carbon dioxide concentration (FAA, 2025a; ASHRAE, 2022) have been measured in some engine exhaust, whereas high UFP count and minimal carbon dioxide elevation have been measured in oil fumes.

5.5.2 Preventive best practices

- a. Where available, install and maintain air cleaning/filtration devices intended to reduce the concentration of ozone, nitrous oxides, VOCs and UFP in the bleed air stream. Inspect and replace those devices at least as often as the manufacturers' recommendations. A VOC/ozone converter will reduce the concentration of some of the VOCs in exhaust fumes during ground operations.³
- b. Flight crew procedures should include measures to minimize exhaust ingestion into the air supply system, including: (i) Do not operate the aircraft engines or APU at the gate unless and until the aircraft is ready to depart or if needed to operate aircraft systems; (ii) Maintain maximum spacing between aircraft and, if possible, orient the aircraft at an angle when waiting in a taxi line so that the air intake is not in line with emissions; and (iii) Apply single-engine taxi procedures to help to reduce overall jet engine emissions in the airport environment.
- c. Ground personnel procedures should include measures to ensure that GSE and vehicles are not operated upwind of a cabin air supply source (APU or PCA). Recurrent training and reminders for ground personnel should emphasize the importance of this to minimize ingestion of exhaust fumes into the cabin.
- d. Where possible, transition to electric GSE or at least operate GSE with ethanol, hydrogen, or other cleaner-burning options. Inspect and maintain ground service vehicles to minimize engine emissions. Shut down ground service vehicles when not in use; do not leave them idling.

5.5.3 Remedial best practices

- a. If exhaust fumes are ingested into the cabin during ground operations, take immediate steps to identify and address the source. If the source is another aircraft in the taxi line, adjust spacing and orientation to avoid the emissions. If the source is GSE or vehicle emissions, shut the unit down or move it to a location that is not upwind of a cabin air source. If emissions are

³ The VOC/ozone converter can only reduce the concentration/count of certain bleed air contaminants during APU and engine ground operations if the bleed air stream is processed by the converter. That ECS configuration is typical, but not universal, so users should review the ECS schematic and procedures in the aircraft flight operations manual.

excessive, the GSE or vehicle should be removed from service for evaluation/repair, in accordance with local procedures.

- b. In many cases, switching the bleed air source (e.g., from APU bleed to engine bleed or vice versa) could provide immediate relief from an exhaust ingestion scenario. Increasing cabin ventilation air flow (if available on the specific aircraft type) may help purge the cabin air of any residual exhaust fumes.

5.6 Fans

5.6.1 Typical scenario

In two reviews of smoke/fume event reports that US airlines sent to the FAA from 2011 to 2022, fans were the third most common cause (Anderson, 2025; Anderson, 2021). The reports cited failures or malfunctions with 22 different types of fans, including (but not limited to) fans in the air supply system. Fan failure is typically identified by a fault message or a tripped circuit breaker. Smoke and fumes from fan failures can be either electrical (from overheated or burned wire insulation, circuit boards, and other components) or mechanical (from failed bearings that result in overheated rotating parts and/or from fan blades rubbing against the housing). Some research has investigated sensor options for smoke/fumes generated by overheated electrical wire and impeller rubbings from a failed recirculated air fan (FAA, 2022 – p.108). Both fan components generated VOCs, including formaldehyde (FAA, 2022 - Table 60).

5.6.2 Preventive best practices

- a. All manufacturer recommendations for fan maintenance – including preventive fan inspections and overhauls – should be followed. Operators may develop additional mitigations based on their experience.
- b. Fan reliability should be monitored by the operator. If trends are identified of premature fan failures on certain aircraft or fleet-wide, corrective actions may be necessary. Note that other system components (mechanical or electrical) may contribute to fan reliability and should be included in the investigation.
- c. The use of ceramic bearings in certain fan applications can improve bearing reliability and may reduce (but not eliminate) the occurrence rate of smoke/fumes sourced to fans.
- d. Vibration or electrical current monitoring technology to proactively shut down the fan prior to failure is incorporated into some fan designs and may be available as an add-on feature in other units.

5.6.3 Remedial best practices

- a. If a fan-related smoke/fume event is suspected, flight crew procedures should include steps to identify, confirm, and isolate the source and to stop/limit the recirculated airflow and increase the outside air ventilation as applicable to the aircraft type.
- b. In response to fan-generated smoke/fumes, maintenance procedures should require that the affected fan be replaced or deactivated (if applicable) before further flight.

5.7 Fuel

5.7.1 Typical scenario

Many jet engine models emit unburned fuel as a part of normal operation, especially during engine start or engine shutdown. Fuel vapors can also be generated during gravity refueling operations (typically used on some small, regional aircraft types). Pressure refueling is the most common fueling method for commercial jets where fuel is pumped under pressure directly into the fuel tanks. Fuel vapors emitted during pressure refueling are minimal, at most. Fuel fumes are normally only entrained into the cabin air supply during ground operations, influenced by the direction of the prevailing wind and whether one or more cabin doors are open. Less commonly, spills or leakage (e.g., from refueling or a failed fuel system component) can result in fuel fumes entering the cabin. Jet fuel is kerosene based, and the fumes contain volatile organic compounds (VOCs), including benzene and toluene (Bendtsen et al., 2021). Fumes from unburned sustainable aviation fuels (SAF plant-based fuels) also contain VOCs, but with more straight-chain hydrocarbons, less aromatic content, and less particulate matter than kerosene-based fuels (Song et al., 2024). Unlike jet fuel, aviation gasoline (“avgas”) used in some small piston-engine aircraft can contain tetraethyl lead which is moderately volatile at room temperature and is added to improve performance.

5.7.2 Preventive best practices

- a. Installing VOC reduction technologies in the bleed air such as VOC filtration and/or VOC/ozone catalytic converters should reduce VOC concentrations (including from fuel vapors) in the ventilation air supplied to the aircraft cabin. If this technology is installed, it should be maintained in accordance with manufacturer recommendations.
- b. Flight crew procedures and training should acknowledge the potential for normal fuel odors versus non-normal fuel odors. For example, transient fuel fumes reported in the aft cabin upon engine shutdown may be a normal phenomenon. However, if the odor is persistent or intense, then it should be investigated further. Neither of these examples is intended to be exhaustive.
- c. If an engine or APU design makes it prone to ingesting fuel that contaminates the air supply system, then routine inspections for fuel leaks are warranted.
- d. The aircraft fuel tank and fuel system maintenance program should include tasks and procedures to minimize the risk of leakage or spills. Inspect the integrity of fuel tank systems (leak checks) during a walk-around inspection as often as manufacturer recommendations.
- e. During refueling operations, ensure that procedures are in place to minimize the potential for fuel odors/vapors to enter the cabin of the aircraft.

5.7.3 Remedial best practices

- a. If fuel fumes are ingested into the cabin during ground operations, take immediate steps to identify and address the source.
- b. In many cases, switching the bleed air source (e.g., from APU bleed to engine bleed or vice versa) could provide immediate relief. Increasing cabin ventilation air flow (if available on the specific aircraft type) may help purge the cabin air of any residual fuel fumes.

5.8 Ozone

5.8.1 Typical scenario

Ozone is primarily produced above the tropopause where ultraviolet light reacts with oxygen. The concentration of naturally produced ozone starts to increase around 26,000 feet at the poles, 50,000 feet at the equator, and continues to rise with altitude up to approximately 90,000 feet. The tropopause drops to lower altitudes in the late winter and early spring (northern hemisphere) and late summer/early fall (southern hemisphere), so ozone concentrations increase at flight altitudes accordingly. During ground operations, ozone gas may also be present as a byproduct of UV light reacting with nitrous oxides in engine exhaust, although typically at lower concentrations than at flight altitudes. Whether inflight or on the ground, ambient ozone gas can be ingested into the aircraft air supply systems. Some ozone will be removed when it is subjected to high temperatures in the engine compressors or it reacts with the inside surface of the air supply ducts; some ozone will be converted into oxygen if a catalytic converter is installed, and some ozone can contaminate the cabin and cockpit supply air. Some aviation authorities (e.g., FAA, Transport Canada) have published design and operating limits for ozone concentration in the cabin (e.g., 14CFR121.578). Some authorities (e.g., EASA) have only published design limits (e.g., CS25.832). In all cases, higher concentrations of ozone are permitted when operating at higher altitudes and ozone monitoring is not required to demonstrate compliance (FAA, 1980).

5.8.2 Preventive best practices

- a. Install and operate an ozone catalytic converter on aircraft assigned to fly routes where elevated levels of ozone are expected to be encountered in flight (see FAA Advisory Circular 120-38 for related information).
- b. Maintain each catalytic converter so that its removal efficiency is always above the minimum allowable efficiency calculated for the specific installation and typical mission profile. Converter removal efficiency can be tested at the manufacturer/repair facility as part of the cleaning/refurbishment process. Exposure to airborne contaminants (e.g., soot, engine oil or hydraulic fluid fumes, etc.) in the bleed air can reduce the removal efficiency of the catalyst by coating its internal surface area.
- c. If ozone converters are not installed, flight routes should be planned to avoid operations within areas of high atmospheric ozone. Integration of atmospheric ozone concentrations into flight planning software could be beneficial.

5.8.3 Remedial best practices

- a. If crew members report onboard conditions consistent with exposure to ozone gas, and if the aircraft is equipped with ozone converters, ensure that the unit's removal efficiency is tested and either meets or exceeds the recommended minimum.

5.9 Lithium-ion batteries

5.9.1 Typical scenario

Lithium-ion batteries are capable of ignition and subsequent explosion after overheating and entering thermal runaway, (FAA, 2009). The primary issue is the potential for an emergency that impacts safety of flight; the secondary issue is the effect on cabin air quality. Dry cell alkaline and rechargeable batteries can also overheat but represent a lower risk of fire. Because of the rise in the use of lithium-ion batteries and reported incidents, Preventive and remedial procedures are necessary (ICAO, 2026; ULSE, 2025; ULSE 2024). Cargo-related lithium-ion battery restrictions and recommendations are not addressed in detail here, but regulations and recommendations have been issued by expert parties including FAA, IATA, ICAO, and ULSE.

5.9.2 Preventive best practices

- a. In initial and recurrent training for cabin crew and pilots, include exercises to teach and reinforce firefighting and emergency response procedures to recognize and respond to lithium battery incidents (ICAO, 2026; FAA, 2017). Also train crews in safe handling and use of battery powered equipment and external power sources.
- b. Ensure that passengers receive clear and dynamic messages about safe transport and use of lithium-ion batteries for each phase of travel (FAA, 2025b), including:
 1. At the point of ticket purchase and check-in, notify passengers in writing that devices powered by lithium-ion batteries are prohibited in checked bags because of the risk of overheating and explosion. To facilitate compliance, educate passengers about the wide range of devices that contain lithium-ion batteries including the obvious (e.g., Personal Electronic Devices, defined in IATA, 2026, such as laptops, phones, smart watches, and external power sources) and less obvious (e.g., e-cigarettes, medical devices, breast pumps, e-toothbrushes). It is preferable to limit each passenger to two external power sources, each with a maximum 100 Watt-hour capacity (ICAO, 2026).
 2. At check-in and at the gate, instruct passengers to keep portable chargers (external power source) within reach in their personal carry-on and not stored in the overhead bins. Also, instruct passengers to not use portable chargers onboard, whether to charge a device or to recharge using seat power (ICAO, 2026). Finally, instruct passengers not to use a "splitter" because they can result in an excessive power draw from a power outlet.
 3. Provide standard PA announcements to instruct passengers that they must disconnect their battery powered equipment from an aircraft power source if there is any sign of battery overheating (such as the equipment feeling hot), place their equipment in clear view.
 4. Instruct wheelchair passengers that, onboard, the battery that powers their mobility device must be stored in a battery containment bag and kept within sight. If the passenger is responsible for the battery containment bag, then this instruction must be made clear

at the point of ticket purchase. If the airline is responsible for the battery containment bag, then it must be available to the passenger either at check-in or at the gate.

5. Instruct passengers that if any PED (e.g., phone, earbuds) gets stuck within a seat assembly, they must notify a cabin crewmember for assistance and not attempt to remove the item themselves.

5.9.3 Remedial best practices

- a. In-cabin procedures for managing overheated batteries should assume that the first cabin crewmember to respond risks incapacitation so will need to receive assistance from a second trained crewmember who has donned a POB (FAA, 2023). Special procedures for single flight attendant operations are necessary. A halon fire extinguisher can be used to extinguish flames but will not cool an overheated device. Crewmembers should be trained to not move an overheated device until it has been thoroughly cooled with water or other nonflammable aqueous substance for at least 15 minutes after any fire/smoke has dissipated (FAA, 2017). The cabin should be equipped with one or more water fire extinguishers to cool an overheated device prior to submerging it in water in a receptacle that is placed away from passengers and monitored by crew (FAA, 2017). Crew may be provided with battery containment bags (ANSI/CAN/ULSE, 2025), but no agency has formally endorsed their use and UL 5800 Level 2 containment bags still allow toxic gases to escape.
- b. During and after an onboard battery incident that generates smoke or fumes, pilot procedures in the Quick Reference Handbook for smoke/fume removal should be implemented to dilute/remove airborne contaminants. These procedures typically involve operating the packs at high flow.
- c. Schedule a crew debrief after any onboard event involving smoke, fumes, or fire sourced to an overheated battery and modify crew training and reporting procedures, as needed.

5.10 Cargo, carry-on bags/belongings

5.10.1 Typical scenario

Carry-on items: Carry-on sources of onboard odors and fumes include items such as lithium-ion batteries, vape pens, dry ice, and perishable food.

Cargo: Air from the cargo hold is not intended to be exchanged with either the cabin or flight deck, but the cargo hold is not hermetically sealed because of pressure changes during a given flight. Under some conditions, airborne contaminants may breach the cargo hold liner and enter the recirculated air stream as a point of entry into either the cabin, flight deck, or both. Problematic items include lithium-ion batteries (refer to Section 5.8), perishable food (e.g., fish, produce), fluid spills, dry ice for shipping perishable products (e.g. FAA, 2020), and live animals.

5.10.2 Preventive best practices

- a. In addition to specific information about lithium-ion batteries, provide passengers with information in simple language upon ticket purchase, check-in, and at the gate that describes items which are not allowed in either the aircraft cabin, checked bags, or both.

- b. Maintain cargo hold liners in a good state of repair with no punctures, tears, or seam gaps.
- c. Perform a safety risk assessment for the transport of certain types of cargo, including a review of their inherent hazardous properties (FAA, 2021).

5.10.3 Remedial best practices

- a. Schedule a crew debrief after any onboard event involving smoke, fumes, or fire involving cargo or carry-on bags/belongings and modify crew training and reporting procedures, as needed.
- b. Spilled liquid material can be especially difficult to clean, especially if it leaks into less accessible areas of the aircraft, including insulation blankets. If a contamination event involves spilled liquid material, extensive open-up and cleaning may be required to avoid repeat reports. If the spilled material is in the vicinity of electrical equipment, additional clean-up, inspections, and/or operational checks may be necessary.

5.11 Dry ice

5.11.1 Typical scenario

Dry ice is the solid form of carbon dioxide with a temperature of -109.3°F (-78.5°C). It may be used in the aircraft galleys, service carts, cargo hold, or within passenger carry-ons to keep perishable items cool, absent proper refrigeration. The maximum weight of dry ice that can be transported is aircraft model-specific and is intended to keep cabin carbon dioxide concentrations below 5,000 ppm (SAFO 20017), which is a component of the international aircraft design standard for ventilation (e.g., 14CFR25.831(b)). With operator approval, passengers and crewmembers may carry up to 5.5lb (2.5 kg) of dry ice per person to transport non-hazardous goods, assuming it is properly labeled and packaged (49CFR175.10(a)(10), 49CFR173.217; IATA, 2026).

5.11.2 Preventive best practices

- a. Ensure that passengers are aware of the restrictions for transporting dry ice in carry-on items and checked baggage, as described above.
- b. If the amount of dry ice onboard (i.e., cargo + cabin) approaches the maximum allowed for the aircraft model, it is recommended to operate the aircraft ECS to maximize the flow of outside air (as available). For example, minimize the duration of ECS OFF and do not operate the ECS in a reduced flow mode.

5.12 Electrical systems

5.12.1 Typical scenario

Malfunction and failure of onboard electrical systems can generate smoke or fumes which are detectable in the aircraft cabin, flight deck, and cargo hold. Sources include fans (Section 5.6), lights, in-flight entertainment systems, flight deck equipment (e.g., windshield heaters), galley equipment (e.g., coffee makers, ovens), cabin lighting, and other aircraft systems. Fumes from

faulty/failed electrical systems contain thermal degradation products of the faulty/failed components (e.g., wire insulation, circuit boards, plastic casing/blades) which will vary by product source and by temperature (FAA, 2024b; Lopez, 2021; Sanders et al., 1978).

5.12.2 Preventive best practices

- a. Train crewmembers and maintenance to promptly report and address electrical faults or failures, ideally before they generate smoke/fumes and before they catch fire.

5.12.3 Remedial best practices

- a. Suitable remedial practices will depend on the electrical fault or failure. For example, overheated electrical devices should be deenergized, and onboard smoke/fumes not sourced to the ventilation system can be diluted by maximizing the outside air flow.
- b. If an electrical component is suspected of causing inflight smoke or fumes, it should be investigated by maintenance before further flight. If maintenance confirms or suspects an electrical item to be the cause, it should be repaired, replaced, or deactivated.

5.13 Flame retardants

5.13.1 Typical scenario

In the US, the FAA neither requires nor bans specific flame retardants but, instead, enforces a design performance standard which dictates that a flame must self-extinguish within 15 seconds under defined test conditions (FAR 14 CFR 25.853 and Appendix F to Part 25). Chemical flame retardants can be applied to many items in the passenger cabin and flight deck, including upholstery, cushions, floor coverings, and crew rest areas. The flame-retardant compounds can be made airborne in dust particles that are generated during normal operations and during cabin cleaning and refurbishment (Strid et al., 2014; Allen et al., 2013)

5.13.2 Preventive best practices

- a. If an operator is involved in selecting which flame retardant to use for cabin interiors, then the less toxic retardants should be chosen.
- b. Workers assigned to cabin cleaning and refurbishment tasks should be provided with suitably protective instructions and PPE (such as gloves and face mask) when engaged in tasks such as cleaning high-dust areas, emptying vacuum bags, replacing old foam cushions, and laying carpet.

5.14 Galley

5.14.1 Typical scenario

Galley equipment (e.g., ovens, coffee makers), perishable food, service carts, trash receptacles, and galley drains are sources of odors and fumes in the passenger cabin. Galley ventilation systems

are designed to be at negative pressure with exhaust that directly exits through the outflow valve and is not recirculated, intended to minimize the spread of galley odors into the cabin.

5.14.2 Preventive best practices

- a. Schedule regular cleaning of the galley floor, service carts, electrical equipment, and ovens.
- b. Ensure that only approved material is placed in the ovens. Unapproved material may produce smoke or produce odors when heated in an oven. If an oven has not been used in some time, or if a new or repaired oven is installed, a “burn in” procedure may be used to ensure any residual foreign material or dust is burnt out or off gassed prior to operation during revenue flight.
- c. Schedule regular removal of trash and sanitize the receptacles.
- d. Ensure that the galley ventilation system filters are replaced at intervals that meet or exceed manufacturer’s recommendations. More frequent filter replacements, system checks, duct cleanings, or fan maintenance may be required to ensure optimal system operation.

5.15 Insecticides

5.15.1 Typical scenario

Airline operators sometimes apply insecticides in the unoccupied aircraft cabin, both in response to insect sightings and what is usually crack and crevice treatment for routine control of cockroaches and other insects. Also, some countries enforce quarantine laws that require incoming aircraft to be sprayed with one or more specific insecticides, either upon or prior to arrival (CDC, 2024). The insecticide application method and surface dosage according to aircraft type must be approved by the World Health Organization (WHO) and will influence exposure potential. Cabin crew can be instructed to spray an aerosol product containing 2% d-phenothrin or 1R-transphenothrin over passengers’ heads either after pushback from the gate (“blocks away”), inflight (“top-of-descent”), or upon arrival (WHO, 2023). Alternatively, surfaces can be “residually” sprayed in the unoccupied cabin and cockpit every 56 days with a solution containing 2% permethrin (WHO, 2023). After residual treatment, an operator must ensure sufficient ground time prior to boarding crew and passengers to ensure that the surfaces are dry. In the US, for a pesticide product to be registered for use on aircraft, manufacturers and registrants must first submit data to the Environmental Protection Agency (EPA) to “demonstrate that the use in occupied aircraft cabins does not pose unreasonable adverse effects to the environment” (EPA, 1996). Currently, there are no disinsection products registered for use in occupied areas (i.e., cabin, flight deck) of aircraft within the US, including its air space. The only currently approved products are for cargo areas. Concerns have been raised over the practice of exposing occupants to insecticide products in an enclosed space (Wei et al., 2012; Sutton et al., 2007). In 2005, the WHO expanded its definition of “disinsection” to include procedures that control (not just kill) insects (WHO, 2024). As a result, mechanical methods of disinsection have been proposed (ICAO, 2016; ICAO, 2010; Carlson et al., 2006).

5.15.2 Preventive best practices

- a. If possible, use mechanical methods to either kill or exclude insects from the aircraft cabin. Any method should be validated by the WHO. Examples include thermal disinsection, high-velocity air across open doors, self-closing net doors for flying insects, and traps for crawling insects.
- b. To ensure that disinsection is justified on incoming flights, request documentation on the threat(s) posed by imported insects, at least annually, from the host country. (ICAO, 2022) Develop and manage a disinsection program for aircraft that may be routed to countries with disinsection requirements.
- c. If chemical disinsection is required, then accomplish residual disinsection with the cabin unoccupied, when permitted by the destination country. Disinsection in an occupied cabin should only be accomplished as a last resort, and only if specifically required by a certain jurisdiction to mitigate a specific insect threat (ICAO, 2022).
- d. Where permitted by the host country's regulations, do not apply insecticides to crew rest modules (including mattresses and bedding), food preparation surfaces, toilet seats, and baby changing tables. Also, ensure that the aircraft is properly ventilated post-spraying, such that the surfaces (including the flight deck, seats, overhead bins) are dry and all areas of the cabin are free of insecticide odors before crewmembers and passengers are expected to board. (Sutton et al., 2007).
- e. Air conditioning packs must be turned off during spraying (and, in some jurisdictions, for five minutes after spraying). Recirculation fans may be left on if they are essential for operation of the aircraft but should be set at the lowest flow rate. Then, operate air conditioning packs on the highest flow setting to clear any remaining aerosol and to dry sprayed surfaces.
- f. Ensure that, as part of the ticket purchase process, passengers are notified about relevant disinsection practices on their flights (49 USC 42303(b)).

5.15.3 Remedial best practice

- a. After residual treatment, if one or more crew members report that cabin surfaces are not dry or that the cabin smells like insecticide, then crewmembers should deplane and boarding not commence until the "dry and odor-free" standard is met.

5.16 Lavatory

5.16.1 Typical Scenario

Lavatory equipment such as toilets, sinks, plumbing, and trash receptacles may be sources of odors in the cabin. In the lavatory, the most common sources of odors are unsanitary conditions and leaks or spills from faulty equipment and clogged drains. Refer also to Section 6.3.

5.16.2 Preventive best practices

- a. During regular service, include procedures to prevent lavatory overflow.
- b. Monitor reports on lavatory related issues (see also Section 6) and implement more frequent service, as needed, on particular aircraft or particular routes.

- c. Develop and follow a robust cleaning and sanitization program for aircraft lavatories to prevent odors.
- d. Ensure that the lavatory ventilation extraction system has sufficient airflow and that the system filters are not clogged.
- e. Implement maintenance procedures to regularly inspect potable water and waste system seals. The pipe seals should be repaired or replaced as necessary to ensure that they do not leak.

5.16.3 Remedial best practices

- a. If the source of the odor is a cleanliness issue, ensure a prompt and thorough response which may require some disassembly of lavatory components.
- b. Some equipment leakage may first appear as a cleanliness issue until further investigated. If a lavatory issue is suspected, system plumbing should be checked for leaks and clogs. This may include removing the toilet shroud and/or inspecting the potable water system plumbing.
- c. If leakage is the source of an odor, it is recommended to also check and address nearby carpets and insulation blankets for residual contamination. If contamination remains in these areas, the odor may persist.

6. INFECTIOUS AEROSOLS

6.1 Introduction

The most recent and significant pandemic to impact the airline industry was the COVID-19 outbreak (WHO, 2020). Onboard exposure control measures included passenger and crew pre-screening, face masks (CDC, 2021; TSA, 2021), limiting food and beverage service, and maximizing the ventilation air supplied to the cabin. Other infectious disease outbreaks that triggered onboard guidance include hanta virus (CDC, 2026), H1N1 (CDC, 2009), tuberculosis (WHO, 2008), and SARS (WHO, 2003). In response to the COVID-19 pandemic, the ASHRAE Epidemic Task Force (ETF) published transportation guidance, including some aircraft-specific recommendations (ASHRAE, 2020). Many of these principles apply to any infectious aerosol on aircraft, and some of the key recommendations are reproduced below, indicated by “ETF.”

ASHRAE Standard 241 (Control of infectious aerosols) establishes minimum requirements to reduce the risk of airborne disease transmission in buildings. The aircraft cabin environment is significantly different, though, in terms of occupant density, ventilation rates, and system design and, therefore, the applicability of ASHRAE Standard 241 to aircraft cabins is limited, at best.

Foodborne and waterborne illnesses spread by the oral-fecal route can put cabin crew and other passengers at risk of infection from contact with contaminated lavatory door handles or other shared surfaces and from exposure to aerosols from bodily fluids (see also Section 5.16).

6.2 Preventive best practices

- a. Collect air flow measurements along the length of the cabin to confirm that air is being properly distributed and corrective action taken where indicated. (ETF)

- b. When risk of infectious disease transmission is elevated, operate air supply systems such that the total per-person ventilation rate in each part of the cabin, as defined in Section 5 of Standard 161, is maximized – even if the cabin is not fully occupied – to minimize the residency time of particulate contaminants, including viruses and bacteria. This includes avoiding single-pack operation and/or low-air-airflow operation. (ETF)
- c. Pass any recirculated air through a filter that at least meets HEPA standard, as defined in Section 6.3 of ASHRAE Standard 161. (ETF)
- d. Minimize the time the ECS is shut down when the cabin is occupied. At a minimum, if the outside air must be shut off, continue to operate the ECS in recirculation mode. (ETF)
- e. Laboratory measurements, modeling studies, and infection data, show that the highest risk location for disease transmission is the seat immediately in front of the source. If empty seats are used to increase spacing, staggered seating should be considered to avoid placing people directly in front of one another. (ETF)
- f. Consider chemical and non-chemical air and surface disinfection options (IATA, 2021). (ETF) Chemical application methods include electrostatic spraying, fogging, and wiping surfaces. Ensure that any product is suitable for aircraft use and does not have negative effects, either on human health or aircraft interiors and components. Confirm that any chemical application method has been approved by the EPA with a suitably conservative unoccupied period post-application before crewmembers board. One non-chemical disinfection option for an unoccupied aircraft on the ground is a portable (“roll-in”) system to expose air and surfaces to UV light.
- g. Other non-ventilation preventive best practices include:
 - 1. Develop protocols for ground personnel and crew to identify and screen passengers who have symptoms of both a fever and either a rash or a persistent cough so that they are not boarded. During operation, if a crew member has reason to be concerned that a passenger is infectious, the person in question should be separated from close contact with others and asked to wear a filtering face mask to reduce the number of droplets coughed into the air, as specified in 14CFR382.51. Screening protocols should also be applied to passengers exhibiting signs of either foodborne or waterborne illness.
 - 2. If not already in use, adopt back to front passenger loading procedures to minimize contact between passengers. (ETF)
 - 3. Make masks, with a protection factor at or above a surgical mask, available to crewmembers and allow crewmembers to wear a face mask in the airport environment and onboard, as they deem necessary.
 - 4. If masks are mandatory, limit food and beverage services to improve passenger compliance. Also, train pilots and cabin crewmembers on common language and procedures to communicate and report non-compliance with face mask rules and related disruptive behaviors.
 - 5. Provide crewmembers and airline cleaning staff with an official document to present to health care and vaccine providers to acknowledge that they are an at-risk work group and should be prioritized along with other front-line workers for immunizations pertaining to the infectious disease hazards that they incur as a result of their duties.
 - 6. Work in close cooperation/coordination with the appropriate local, state/provincial, and national health authorities. (ETF)

6.3 Remedial best practices

- a. If a symptomatic passenger is onboard an aircraft in operation, ensure that cabin crew members follow basic protocols for infection control (whether via infectious aerosols or the fecal-oral route). This should include the cabin crew donning PPE (i.e., gloves, mask). Also, ill passengers should be isolated, instructed to wear a face mask, and provided with a dedicated lavatory, if appropriate and feasible (see also Section 5.16). (ETF) Also, provide masks to other occupants, especially those seated near the infected person, especially if relocating passengers is either not possible or limited. (ETF)
- b. If a crew member suspects an aircraft occupant of being ill with a communicable disease per 42 CFR 71.1 or equivalent, the illness shall be reported to the nearest cognizant quarantine station per 42 CFR 71.21(b) or equivalent. A passenger manifest should be maintained to aid in contact tracing.
- c. Allow any crewmember and customer service agent who had reasonable exposure to a potentially infectious person to quarantine without losing pay to limit additional spread of pathogens.
- d. Work in close cooperation/coordination with the appropriate local, state/provincial, and national health authorities, including reporting and contact tracing. (ETF)
- e. Disinfect onboard surfaces and operate ECS on maximum airflow setting. Ensure that cleaning staff are provided with suitably protective PPE, including face masks and gloves.

(This appendix is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

INFORMATIVE APPENDIX A

INFORMATIVE REFERENCES

Aeroparts (2024) Controlled VOC ozone converter testing. Discussion paper DP-02. Presented to SAE Aerospace Aircraft engines gas and particulate emissions measurement committee (E-31) in Jan. 2024 and shared with ASHRAE. Used with permission; may be cited; <https://perma.cc/DRS7-EM2L>.

Allen, JG; Stapleton, HM; Vallarino, J. *et al.* (2013) Exposure to flame retardant chemicals on commercial airplanes. *Environ Health* **12**, 17, <https://doi.org/10.1186/1476-069X-12-17>.

Anderson, J. (2021) Sources of onboard fumes and smoke reported by US airlines. *Aerospace*, 8(5): 122, <https://doi.org/10.3390/aerospace8050122>.

Anderson, JTL. (2025) Lessons learned from official airline reports of onboard fumes and smoke. *Aerospace*, 12(5), 437, <https://doi.org/10.3390/aerospace12050437> and <https://doi.org/10.5281/zenodo.17088714>.

ANSI/CAN/ULSE (2025) Standard 5800: Battery fire containment products. American National Standards Institute/Standards Council of Canada/UL Standards and Engagement. First published 8-Dec-2020; Revised and ANSI and CAN approved 6-May-2025. Available via <https://www.shopulstandards.com/>

ASHRAE (2020) Guidance for Transportation. ASHRAE Epidemic Task Force, ASHRAE. Updated 20-Nov-2020. Available via <https://www.ashrae.org> or at <https://perma.cc/XL93-ERJL>.

ASHRAE (2023) Standard 241: Control of Infectious Aerosols.

ASHRAE (2022) Research Project 1830: Experimental characterization of aircraft bleed air particulate contamination. Principal Investigator: Byron Jones; Authored by Alan Levin; Sponsored by TC9.3 Transportation Air Conditioning.

BASF (2026) Revolutionize cabin air quality with our new VOZC technology. Marketing data posted online: <https://basf-catalystsmetals.com/en/catalysts/aerospace/vozc#key>.

Bendtsen, KM, Bengtsen, E, Saber, AT *et al.* (2021) A review of health effects associated with exposure to jet engine emissions in and around airports. *Environ Health* **20**, 10, <https://doi.org/10.1186/s12940-020-00690-y>.

Carlson, DA; Hogsette, JA; Kline, DL; *et al.* (2006) Prevention of mosquitoes (Diptera: Culicidae) and house flies (Diptera: Muscidae) from entering simulated aircraft with commercial air curtain

units, *J of Economic Entomology*, Vol. 99(1): 182-193. doi: 10.1603/0022-0493(2006)099[0182:pomdca]2.0.co;2.

CDC (2009) H1N1: Interim guidance for airlines regarding flight crews arriving from domestic and international areas affected by Swine Influenza. US Centers for Disease Control and Prevention, Atlanta, GA, <https://perma.cc/ALP8-BP7Y>.

CDC (2021) Requirement for persons to wear masks while on conveyances and at transportation hubs, 42 USC 264 Sect. 361 and 42 CFR Sect. 70.2, 71.31(b), and 71.32(b).

CDC (2024) Aircrew and pesticides. National Institute for Occupational Safety and Health, US Centers for Disease Control and Prevention, Atlanta, GA, <https://www.cdc.gov/niosh/aviation/prevention/aircrew-pesticides.html> or <https://perma.cc/35M2-GMKE>.

CDC (2026) Interim guidance for public health assessment and management of people with potential exposure to Andes Virus. National Institute for Occupational Safety and Health, US Centers for Disease Control and Prevention, Atlanta, GA, <https://www.cdc.gov/hantavirus/php/emergency-guidance/index.html> or <https://perma.cc/GAP6-A79B>.

EPA (1996) Pesticide Registration Notice 96-3: Pesticide products used to disinsect aircraft. US Environmental Protection Agency, Washington, DC. 14-May-1996; <https://www.epa.gov/pesticide-registration/prn-96-3-pesticide-products-used-disinsect-aircraft> or <https://perma.cc/ZNK6-TWK4>.

FAA (1980) Advisory Circular 120-38: Transport category airplanes cabin ozone concentration. 10-Oct-1980. Federal Aviation Administration, Flight Operations, Washington, DC.

FAA (1986) Advisory Circular 120-12A: Private carriage versus common carriage of persons or property. Initiated by AFS-820, signed by William T. Brennan, Acting Director of Flight Standards, US Federal Aviation Administration, 24-Apr-1986. Available via https://www.faa.gov/regulations_policies/ or <https://perma.cc/MK3N-AKCI>.

FAA (2009) SAFO 09013: Fighting fires caused by lithium type batteries in portable electronic devices. 23-June-2009. Federal Aviation Administration, Flight Standards Service, Washington, DC. Available via <https://www.faa.gov> or <https://perma.cc/2RGJ-8H68>.

FAA (2017) InFO Notice 17021: Risk associated with the use of fire containment products by Title 14 of the Code of Federal Regulations (14 CFR) Part 91 subpart K (91K), 121, 125 and 135 Operators. 26-Dec-2017. Federal Aviation Administration Flight Standards Service, Washington, DC. Available via <https://www.faa.gov> or <https://perma.cc/6VU9-7WX9>.

FAA (2020a) Advisory Circular 150/5300-14D: Design of aircraft deicing facilities. Issued Mar. 17, 2020. AAS-100, Office of Airport Safety & Standards - Airport Engineering Division, US Federal Aviation Administration, Washington, DC. Available via <https://www.faa.gov>.

FAA (2020b) Transportation of COVID-19 vaccines requiring large quantities of dry ice. Safety Alert for Operators (SAFO) 20017. Issued 10-Dec-2020, Flight Standards Service, US Federal Aviation Administration, Washington, DC. Available via <https://www.faa.gov> or <https://perma.cc/6RLR-VJBR>.

FAA (2021) Advisory Circular 120-121: Safety risk management involving items in aircraft cargo compartments. Issued 1-Sept-2021. Flight Standards Service (AFS-300), Federal Aviation Administration, Washington, DC. Available via <https://www.faa.gov>.

FAA (2022) Aircraft air quality and bleed air contamination detection. Report no. DOT/FAA/TC-21/45; Authored by Jones, BJ. Supported by US Department of Transportation. Federal Aviation Administration, Aviation Research Division, Atlantic City, NJ, May-2022, <https://doi.org/10.21949/1524479>.

FAA (2023) Advisory Circular 120-80B: Firefighting of general and high-energy in-flight fires. Issued 16-Mar-2023. Flight Standards Service (AFS-300), Federal Aviation Administration, Washington, DC. Available via <https://https://www.faa.gov>.

FAA (2024a) Aircraft air quality and bleed air contamination detection: Engine stand tests, sensor technologies and chemical sampling. Phase 2, Volume 1. Report no. DOT/FAA/TC-23/46; Authored by Fox, RB and Jones, BJ. Supported by the US Department of Transportation, Federal Aviation Administration, Aviation Research Division, Atlantic City, NJ, Apr-2024, <https://doi.org/10.21949/1524480>.

FAA (2024b) Detection of signatures from internal contaminant sources using intelligent algorithms. Authored by Anthrathodiyil, S. Report no. DOT/FAA/TCTT-24/10, Federal Aviation Administration, William J. Hughes Technical Center, Aviation Research Division, Atlantic City, NJ. https://rosap.ntl.bts.gov/view/dot/74236/dot_74236_DS1.pdf.

FAA (2025a) Aircraft air quality and bleed air contamination detection: Engine stand tests, sensor technologies and chemical sampling. Phase 2, Volume 2. Report no. DOT/FAA/TC-23/46 V2; Authored by Fox, RB and Jones, BJ. Supported by the Federal Aviation Administration, Aviation Research Division, Atlantic City, NJ, Jan-2025, <https://rosap.ntl.bts.gov/view/dot/79601>.

FAA (2025b) SAFO 25002: Managing the risks of lithium batteries carried by passengers and crew members. Safety Alert for Operators, Flight Standards Service, Federal Aviation Administration, Washington, DC. 8-Aug-2025, <https://www.faa.gov> or <https://perma.cc/F2M2-BLZG>.

Fushimi, A; Saitoh, Y; Fujitani, Y; et al. (2019) Identification of jet lubrication oil as a major component of aircraft exhaust nanoparticles. *Atmospheric Chemistry and Physics*, 19(9) 6389-6399, <https://doi.org/10.5194/acp-19-6389-2019>.

IATA (2021) Aircraft cleaning and disinfection during and post pandemic, Ed. 2. 22-Jan-2021. International Air Transport Association, Montreal, Canada. Available via <https://www.iata.org/>.

IATA (2026) Dangerous Goods Regulations Manual, ed. 67. International Air Transport Association, Montreal, Canada.

ICAO (2010) A37-13: Non-chemical disinsection of the aircraft cabin and flight deck for international flights. In Resolutions Adopted by the Assembly, 37th Session, Sept. 28 - Oct. 8, 2010. International Civil Aviation Organization, Montreal, Canada.

ICAO (2015) Guidelines on education, training, and reporting practices related to fume events. Circular 344-AN/202. International Civil Aviation Organization, Montreal, Canada, 2015. Available for purchase online via <https://www.icao.int>.

ICAO (2016) The need for risk assessment guidance and performance-based criteria in aircraft disinsection. Working Paper 84, presented by the United States at ICAO Assembly, 39th Session, Executive Committee, Aug. 17, 2016, <https://www.icao.int/Meetings/a39/> or <https://perma.cc/2PRN-D726>.

ICAO (2022) Annex 9 to the Convention on International Civil Aviation: Facilitation (16th Ed.), International Civil Aviation Organization, Montreal, Canada.

ICAO (2026) Technical instructions for the safe transport of dangerous goods by air. 2025-26 Edition, Addendum 1; effective Mar. 27, 2026. International Civil Aviation Organization, Montreal Canada. Available via: <https://www.icao.int/>.

Lopez, G. (2021) High-performance polymers for aeronautic wires insulation: Current uses and future prospects. Recent Progress in Materials, 3(1): 005. <https://doi.org/10.21926/rpm.2101005>.

Nurcombe, C. (2005) Airbus cabin air quality - still the best! Flight Airworthiness Support Technology – Airbus technical magazine. Issue 37: 7-10, Airbus SAS, <https://aircraft.airbus.com/sites/g/files/jlcbta126/files/2022-04/FAST37.pdf>.

Rolls Royce (2014) Bearing chamber venting system for an aircraft engine and method for providing a required pressure ration at bearing chamber seals of an air-sealed bearing chamber. Patent no. US 2014/096533-A1; Sections [0007], [008], and [041], <https://patents.justia.com/patent/20140096533>.

SAE (2021) Airborne chemicals in aircraft cabins, Aerospace Information Report 4766/2 Revision A. SAE Aerospace, Warrendale, PA, <https://www.sae.org/standards/content/air4766/2a/>.

Sanders, DC; Endecott, BR; Sanders, DC; et al. (1978) Electrical insulation fire characteristics, Vol. II: Toxicity. Report no. UMTA-MA-06-0025-79-2, II. Prepared for the Urban Mass Transit Administration, US Department of Transportation by the Civil Aeromedical Institute, Federal Aviation Administration, Oklahoma City, OK. Dec-1978, https://rosap.ntl.bts.gov/view/dot/11408/dot_11408_DS1.pdf.

Solbu, K; Dae, HL; Thorud, S. et al. (2010) Exposure to airborne organophosphates originating from hydraulic and turbine oils among aviation technicians and loaders. J of Environ Monitoring, 12:2259–68, <https://doi.org/10.1039/c0em00273a>.

Song, Z.; Li, Z.; Liu, Z. (2024) Comparison of emission properties of sustainable aviation fuels and conventional aviation fuels: A review. *Appl. Sci.* 2024, 14, 5484, <https://doi.org/10.3390/app14135484>

Strid, A; Smedje, G; Athanassiadis, I; et al. (2014) Brominated flame-retardant exposure of aircraft personnel. *Chemosphere*. 116: 83-90, doi: 10.1016/j.chemosphere.2014.03.073. Epub 2014 Apr 16. PMID: 24745557.

Sutton, PM; Vergara, X; Beckman, J, et al. (2007) Pesticide illness among flight attendants due to aircraft disinsection. *Am J Ind Med*. 2007 May;50(5):345-56, doi: 10.1002/ajim.20452.

TSA (2021) Security measures – face mask requirements, Security Directive (SD) 1582/84-21-01. Transportation Security Administration, Washington, DC, <https://www.tsa.gov/sites/default/files/sd-158284-21-01.pdf> or <https://perma.cc/Y4MQ-TVSP>.

ULSE (2024) Lithium-ion battery incidents and their impact on aviation safety. UL Standards and Engagement, Northbrook, IL, <https://ulse.org/insight/data-insights-lithium-ion-battery-incidents-and-their-impact-aviation-safety/>.

ULSE (2025) Lithium-ion battery incidents in aviation: 2024 data review. UL Standards and Engagement, Northbrook, IL, <https://ulse.org/wp-content/uploads/2025/06/TRIP-Report-May-2025-Final.pdf>.

Ungeheuer, F; van Pinxteren, D; and AL Vogel. (2021) Identification and source attribution of organic compounds in ultrafine particles near Frankfurt International Airport. *Atmospheric Chemistry and Physics*, 21(5): 3763–3775, <https://doi.org/10.5194/acp-21-3763-2021>.

Wei, B; Mohan, KR; and Weisel CP. (2012) Exposure of flight attendants to pyrethroid insecticides on commercial flights: urinary metabolite levels and implications. *Int J Hyg Environ Health*. 2012 Jul;215(4):465-73, doi: 10.1016/j.ijheh.2011.08.006. Epub 2011 Sep 21.

WHO (2003) WHO-recommended measures for persons undertaking international travel from areas affected by Severe Acute Respiratory Syndrome (SARS). *Weekly Epidemiological Record*, No. 14(78): 97-99, Available via <https://www.who.int/> or <https://perma.cc/5EU4-JJRX>.

WHO (2008) Tuberculosis and air travel. Guidelines for prevention and control, 3rd Ed. Report no. WHO/HTM/TB/2008.399. World Health Organization, Global Programme on Tuberculosis and Lung Health, Geneva, Switzerland. Available via <https://iris.who.int/> or <https://perma.cc/9JB2-UEBY>.

WHO (2020) Timeline: WHO's COVID-19 response. World Health Organization, Geneva, Switzerland. Available via <https://www.who.int> or <https://perma.cc/77F3-GXJ4>.

WHO (2023) WHO aircraft disinsection methods and procedures. World Health Organization, Geneva, Switzerland, <https://www.who.int/publications/i/item/9789240080317> or <https://perma.cc/NV9M-43K6>.

WHO (2024) International Health Regulations. Originally published 2005 with amendments in 2012, 2022, 2024. World Health Organization, Geneva, Switzerland, https://apps.who.int/gb/bd/pdf_files/IHR_2014-2022-2024-en.pdf