AEROSPACE INFORMATION REPORT

AIR1539™	REV. C

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Superseding AIR1539B

(R) Environmental Control System Contamination

RATIONALE

AIR1539C references have been updated and design considerations provided for relevant atmospheric and ground air supply contaminants. Gaseous atmospheric contaminants that affect ECS and fuel tank inerting systems are also discussed.

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1. SCOPE

This SAE Aerospace Information Report (AIR) includes a discussion of liquid and particulate contaminants which enter the aircraft through the environmental control system (ECS). Gaseous contaminants such as ozone, fuel vapors, sulphates, etc. are also covered in this AIR. This publication is concerned with contamination sources which interface with ECS and fuel tank inerting systems, and the effects of this contamination on equipment. Methods of control will be limited to the equipment and interfacing ducting which normally falls within the responsibility of the ECS designer.

1.1 Purpose

The purpose of this AIR is to categorize sources of ECS contaminants, define the effects of these contaminants on equipment, and outline design features that can be used to control contamination in aircraft systems.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific examption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR910 Ozone in High Altitude Aircraft

AIR4766 Air Quality for Commercial Aircraft Cabins

AIR4766/1 Air Quality for Commercial Aircraft Cabin Particulate Contaminants

AIR4766/2 Airborne Chemicals in Aircraft Cabins

AIR7521 Measurement Data and Reference Values for Compounds Potentially Found in Aircraft Engine Bleed Air

2.1.2 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

AC 120-38. [1980]. Transport Category Airplanes Cabin Ozone Concentrations.

2.1.3 EASA Publications

Available from European Union Aviation Safety Agency, Konrad-Adenauer-Ufer 3, D-50668 Cologne, Germany, Tel: +49.221.89990.1000, www.easa.europa.eu.

CS-E. Engines.

2.1.4 ASHRAE Publications

Available from ASHRAE Headquarters, 1791 Tullie Circle, NE, Atlanta GA 30329, Tel: 800-527-4723 (U.S. and Canada only) or 404-636-8400, www.ashrae.org.

ASHRAE Handbook. [1977]. Fundamentals.

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2.1.5 Other Applicable Publications

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2.2 Definitions

AEROSOL: A suspension in a gaseous medium of solid particles, liquid particles, or solid and liquid particles having a negligible falling velocity (ISO 7708, 1995).

BLEED AIR: As used in this document, air from outdoor origin entering cabin after having been processed through an engine compressor, turbo compressor, or shaft-driven compressors.

2.3 Acronyms and Abbreviations

µm	Micron/Micrometer
AC	FAA or EASA Advisory Circular
ACM	Air Cycle Machine
APU	Auxiliary Power Unit
ASHRAE	American Society for Heating, Refrigerating, and Air Conditioning Engineers
CFC-11	Pentachlorofluoroethane

CH_3Cl	Methylene Chloride, Dichloromethane
CH_3OOH	Methyl Hydroperoxide
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
ECS	Environmental Control System
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration (USA)
H_2S	Hydrogen Sulfide
HCN	Hydrogen Cyanide
HF	Hydrogen Fluoride
hPa	Hectopascal (Pressure)
ICAO	International Civil Aviation Organization
ISO	International Standard Organization
mm Hg	Millimeters of Mercury (Pressure)
NASA	National Aeronautics and Space Administration
NO	Nitric Oxide
NO_y	Nitrogen Oxides
O_3	Ozone
PAN	Peroxyacetylnitrate
ppbV	Parts per Billion in Volume
ppmV	Parts per Million in Volume
pptV	Parts per Trillion in Volume
SO_2	Sulfur Dioxide

3. TYPES AND SOURCES OF CONTAMINATION

Two types of contamination are of concern to ECS design. Particulate contaminants include sand and dust, metal, and carbonaceous material. Refer to AIR4766/1 for a more in-depth discussion on particulate contaminants in aircraft ECS systems. Chemical contaminants may be generated within aircraft components or be present in the operating environment, and potentially can be introduced into the cabin through the ECS. Refer to AIR4766/2 for a more in-depth discussion regarding gaseous contaminants that may be present within the bleed air supply and in recirculated cabin air.

3.1 Sources of Chemical Contamination

3.1.1 Tropospheric and Stratospheric Contaminants

The troposphere is the lowest layer of our atmosphere (Figure 1) as depicted by Russell [2015]. Starting at ground level, it extends upward to about 10 km (6.2 miles or about 33000 feet) above sea level. Tropospheric gaseous contaminants are in the operating aircraft envelope at cruise altitudes. The next atmospheric layer is called the stratosphere. The stratosphere extends from the top of the troposphere to about 50 km (31 miles) above the ground. The ozone layer is within the stratosphere. Atmospheric temperature gets warmer as you go higher in the stratosphere (Russell. [2015]).

Several recent studies provide information that is valuable for aircraft designers to understand potential long-term exposure effects of atmospheric gaseous contaminants.

- Methanol is present at 1 to 15 ppbV in continental boundary layer and 0.1 to 1 ppbV in remote troposphere (Figure 2), per Caravan et al. [2018].
- Tropospheric levels of sulfur dioxide are in the parts per trillion range (pptV). NO, NO_y, and SO_2 are greater in contrails, but still in ppbV and pptV levels and are depicted by Speidel et al. in their Figure 8 (Speidel et al. [2007]).
- Measured levels of sulfur dioxide are in the pptV range and are depicted by Speidel et al. in their Figure 5 (Speidel et al. [2007]).
- Carbon monoxide production occurs from methane oxidation reactions and dissociation of CO_2 in the atmosphere (Minschwaner et al. [2010]). CO range is in the ppbV level (Minschwaner et al. [2010]).
- Chlorinated hydrocarbons from volcanic eruptions and solid rocket fuels do not survive transport to the stratosphere and are washed out in the troposphere (Figure 3) (Von Clarmann. [2013]).
- Hydrogen sulfide emission simulations estimate 10 pptV emissions of H_2S with emissions measured for the study. Tropospheric levels of H_2S may increase to 140 ppbV with elevated surface emission levels. The measurements of Lamarque et al. [2007] are presented in Figure 4.
- Ozone is present seasonally in certain regions of the troposphere. Section 3.1 of AIR910 provides additional detailed information on atmospheric ozone levels. Figures 5 (NASA Ozone Watch. [2018]), 6 (Bhangar and Nazaroff. [2013]), and 7 (Cooper et al. [2014]) provide further information on the levels and variability of ozone concentrations.

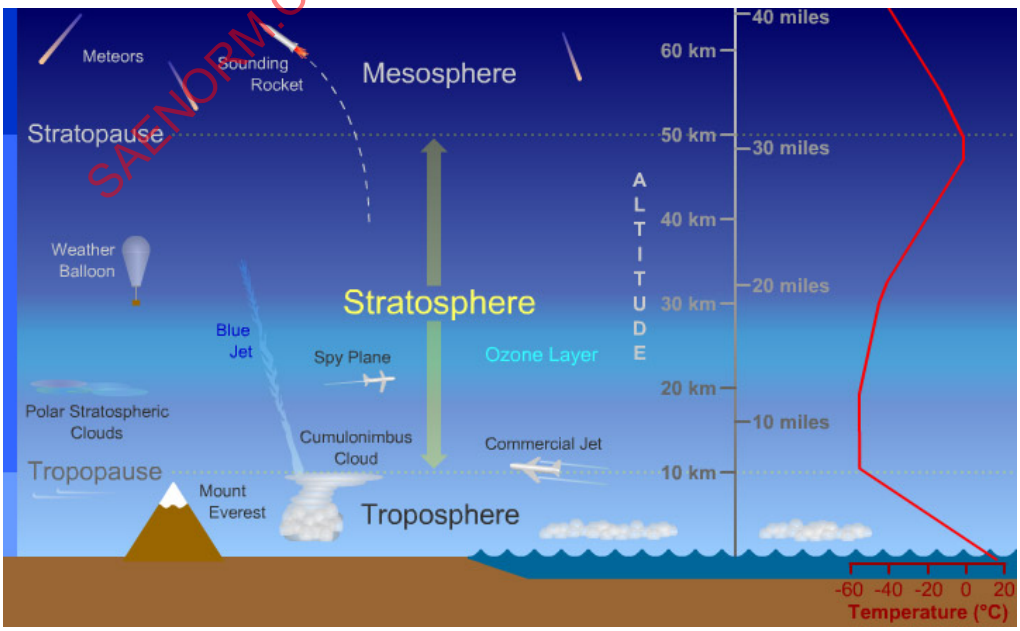

Figure 1 - Atmospheric layers

A study of flights made by Bhangar and Nazaroff [2013] presents measured average and peak values for flights between 2000 and 2005. The study discusses seasonal shifts in ozone concentration and stratosphere to troposphere exchange of ozone, as well as ozone level with respect to flight altitude (Figure 6).

Global distribution and trends of tropospheric ozone have been published by the IPCC [2013] and modified with trendlines in a review by Cooper et al. [2014]. The designer of ozone converters should be aware that ozone levels in the troposphere have been trending upwards from the original measurements obtained during the GASP study (NASA. [1981]; NASA. [1984]). In addition, surface ozone increases have also been measured in some locations and seasons, while decreasing in others. Europe has oldest records of ozone levels and it has been observed that ozone concentrations there doubled between the 1950s and 2000 (Cooper et al. [2014]). Western Europe levels have leveled off or decreased since 2000, while Eastern USA levels have decreased strongly in summer, remain unchanged during the spring, and increase during the winter. Meanwhile, surface ozone concentrations in East Asia are on the rise, according to Cooper et al.

Figure 7 depicts seasonal ozone concentrations as parts per billion by volume (ppbV) (Cooper et al. [2014]). Design and qualification test considerations for ozone converters and air separation membrane pre-filters include worst-case seasonal exposure. FAA Circular AC 120-38 recommends design of ozone converters to be able to reduce levels of ozone as high as 1.3 ppmV (1300 ppbV) found in AC 120-38, section 2.j. This level is greater than the 600 ppbV listed in Table 1. Table 1 only provides approximate values, and not maximum instantaneous values that might be encountered.

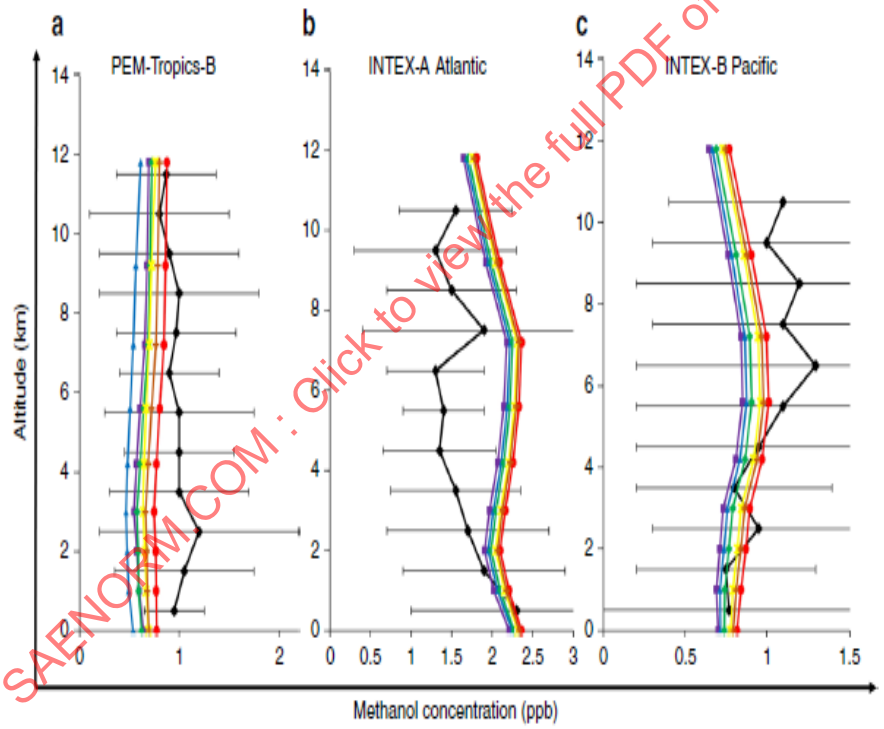

Figure 2 - Methanol measured at altitude
© Caravan, R.L., Khan, M.A.H, Zádor, J., et al. [2018].
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Detected SO_2, NO, and NO_y levels during crossing of an aircraft contrail. All trace gases are strongly enhanced abover atmospheric concentrations measured before interception.

Vertical SO_2 mixing ratios of two ITOP flights performed 26 July and 31 July. See reference for more details.

Zonal mean carbon monoxide mixing ratios measured by MLS and averaged over 15-day periods centered on the equinoxes. Data are version 2.2, daytime measurements for (top) March 2005 and (bottom) September 2005 of Minschwaner et al [2007] in their Figure 1.

CFC-11 in March 2011 over altitude and latitude. This monthly mean distribution has been calculated on the basis of MIPAS measurements (Kellmann et al. [2012]). In the lower tropical atmosphere, mixing ratios are largest because air has not yet been exposed to hard ultraviolet radiation for a long time. Following the stratospheric circulation, mixing ratios decrease with altitude and latitude, reflecting loss by photolysis. Particularly low mixing ratios over the North Pole are caused by subsidence of CFC-poor air from high altitudes.

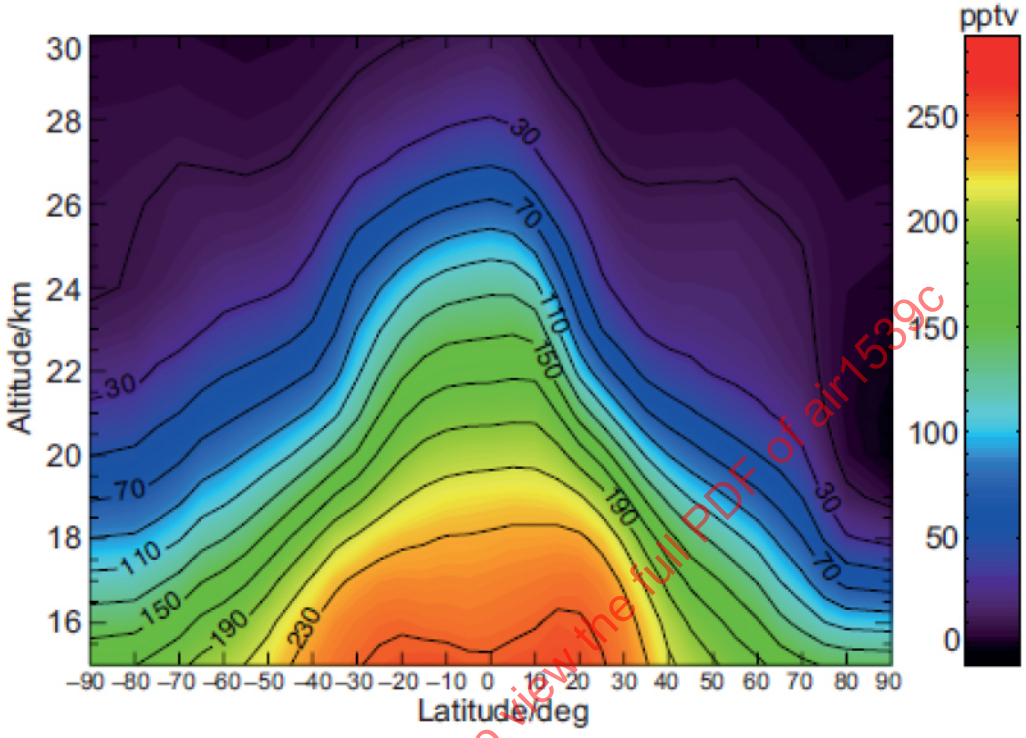

Figure 3 - CFC-11 measured at altitude

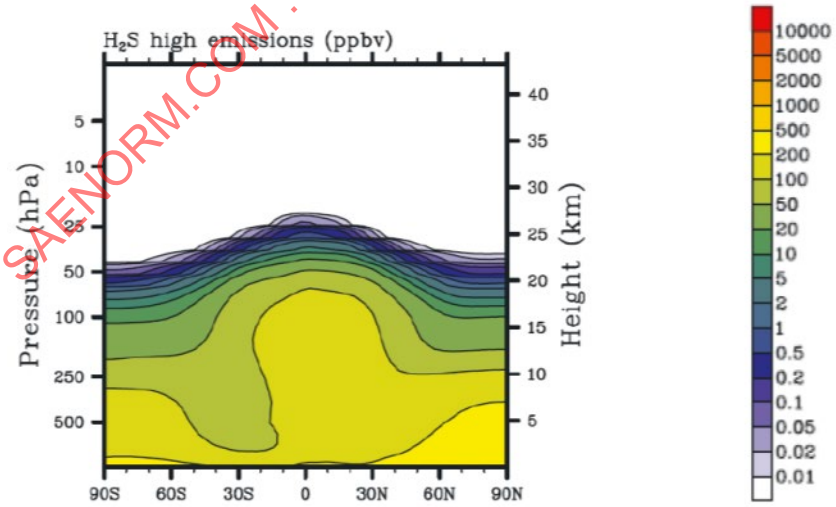

Figure 4 - Hydrogen sulfide measured at altitude

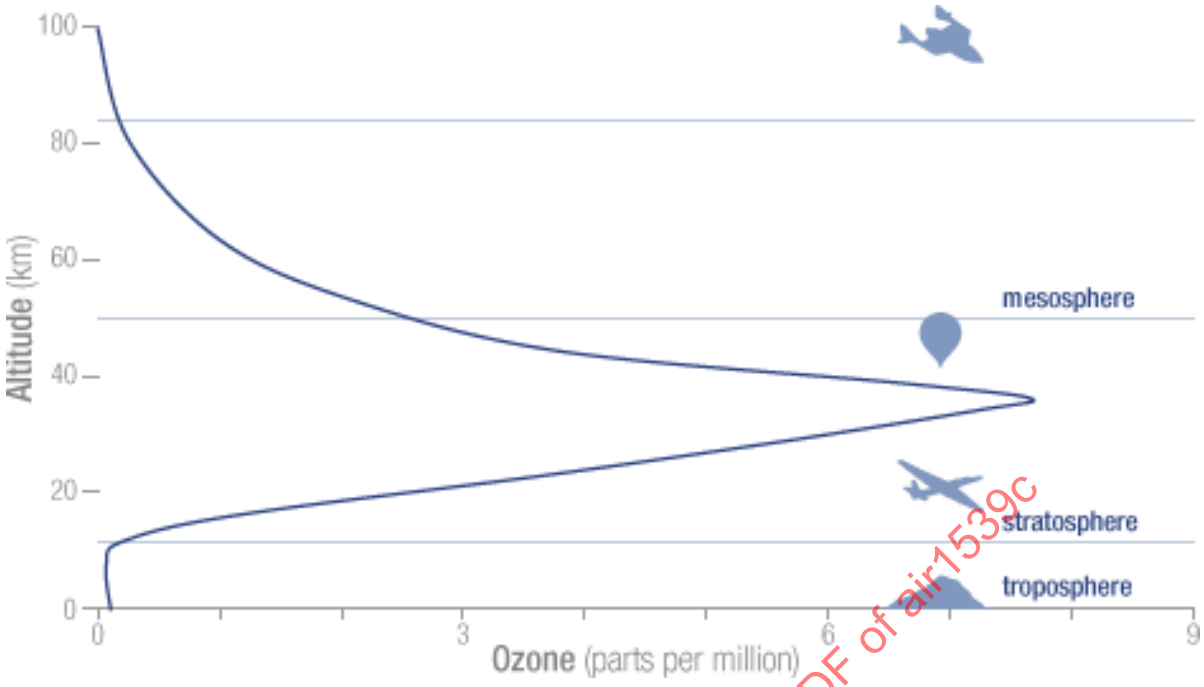

Figure 5 - Ozone measured at altitude
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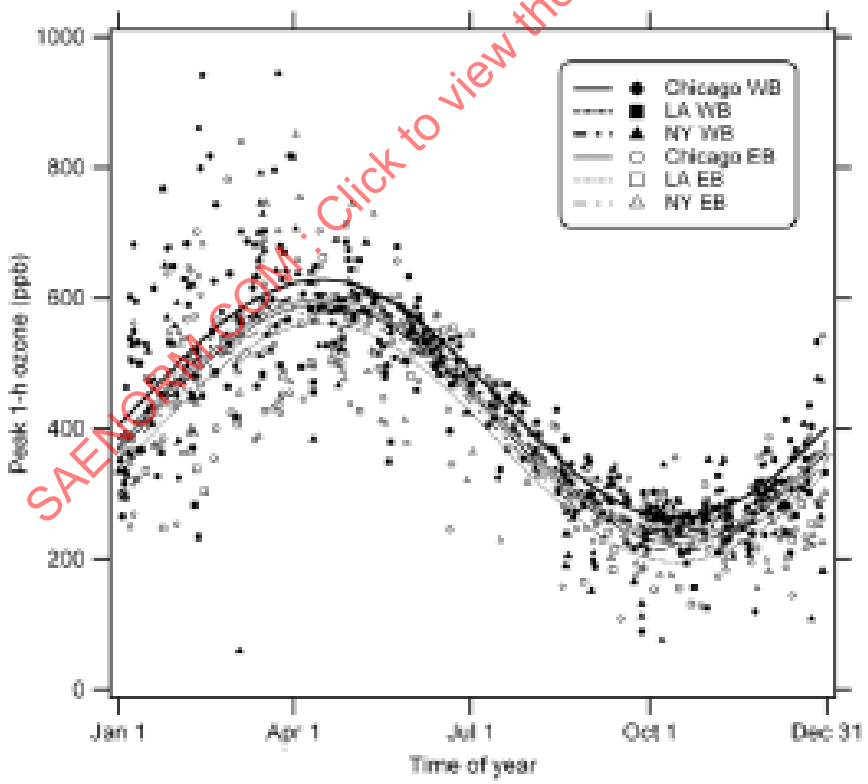

Figure 6 - Ozone measured in flight (5-year period)
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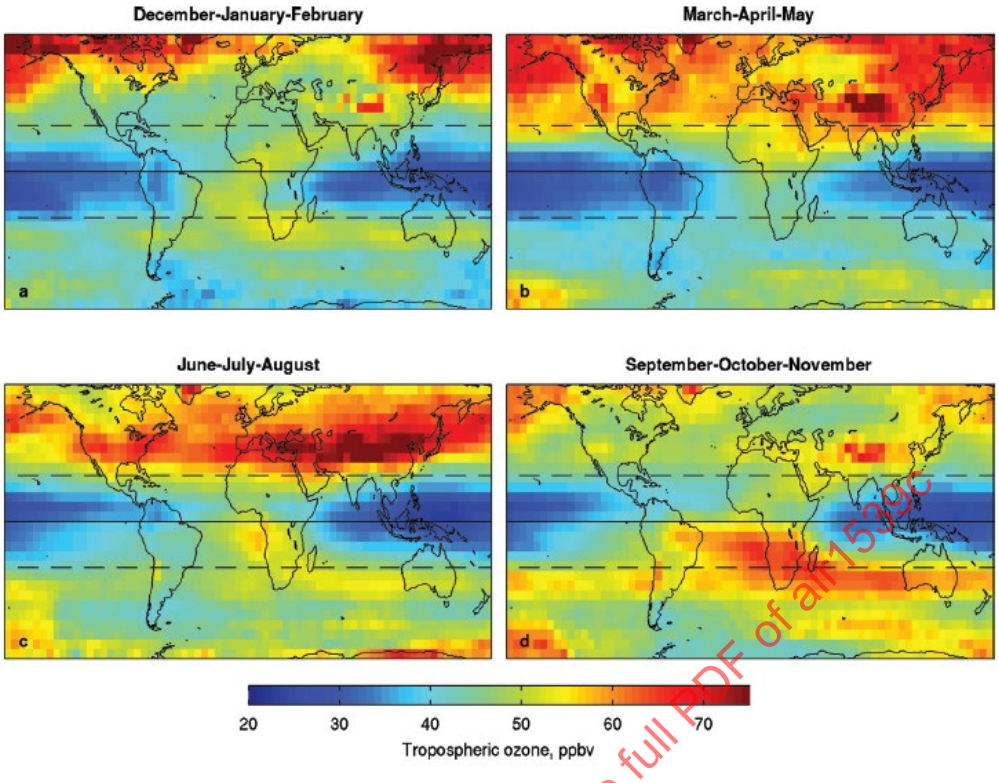

Figure 7 - Global ozone distribution
© Cooper et al. [2014]. Reproduced with permission.
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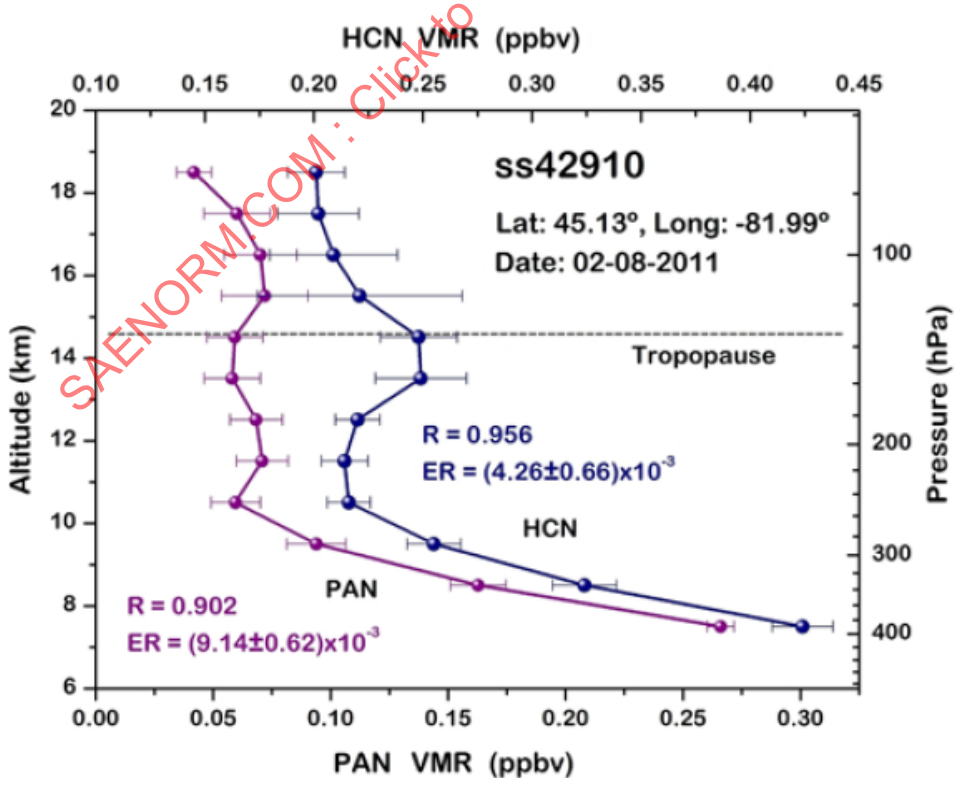

Figure 8 - PeroxyacetylNitrate measured at altitude
© Tereszchuk et al. [2013]. Reproduced with permission.
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Peroxyacetylnitrate and cyanide are present in the troposphere and stratosphere from combustion processes (Tereszchuk et al. [2013]). Figure 8 depicts some measured concentrations at one measurement site.

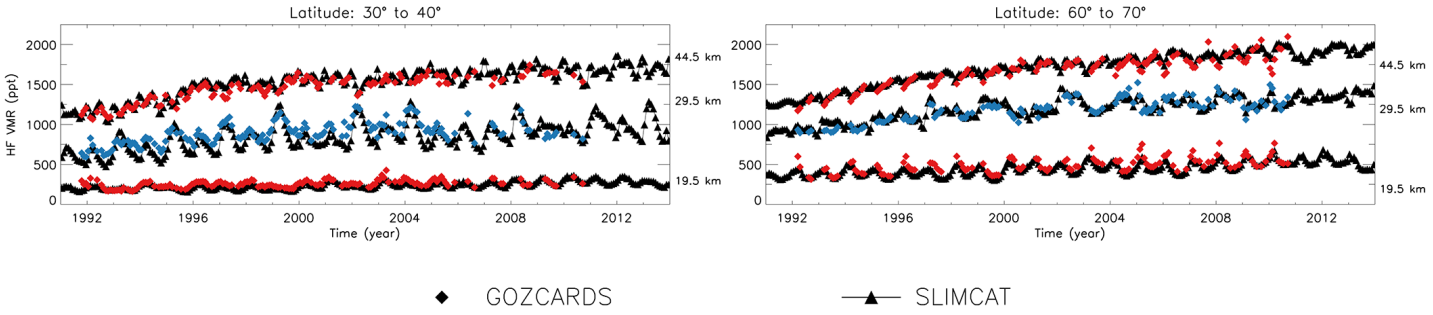

Figure 9 - Hydrogen fluoride measured at latitude
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Hydrogen fluoride (HF) is sourced from decomposition of fluorinated refrigerants in the stratosphere to form hydrogen fluoride. Figure 9 depicts measurements of HF at several latitudes and altitudes presented by Harrison et al. [2016].

Atmospheric methane concentration is globally variable above the lower troposphere (Worden et al. [2015]). Sources can include wetlands and anthropogenic emissions. Figure 10 provides a range of concentrations presented by Worden et al. [2015].

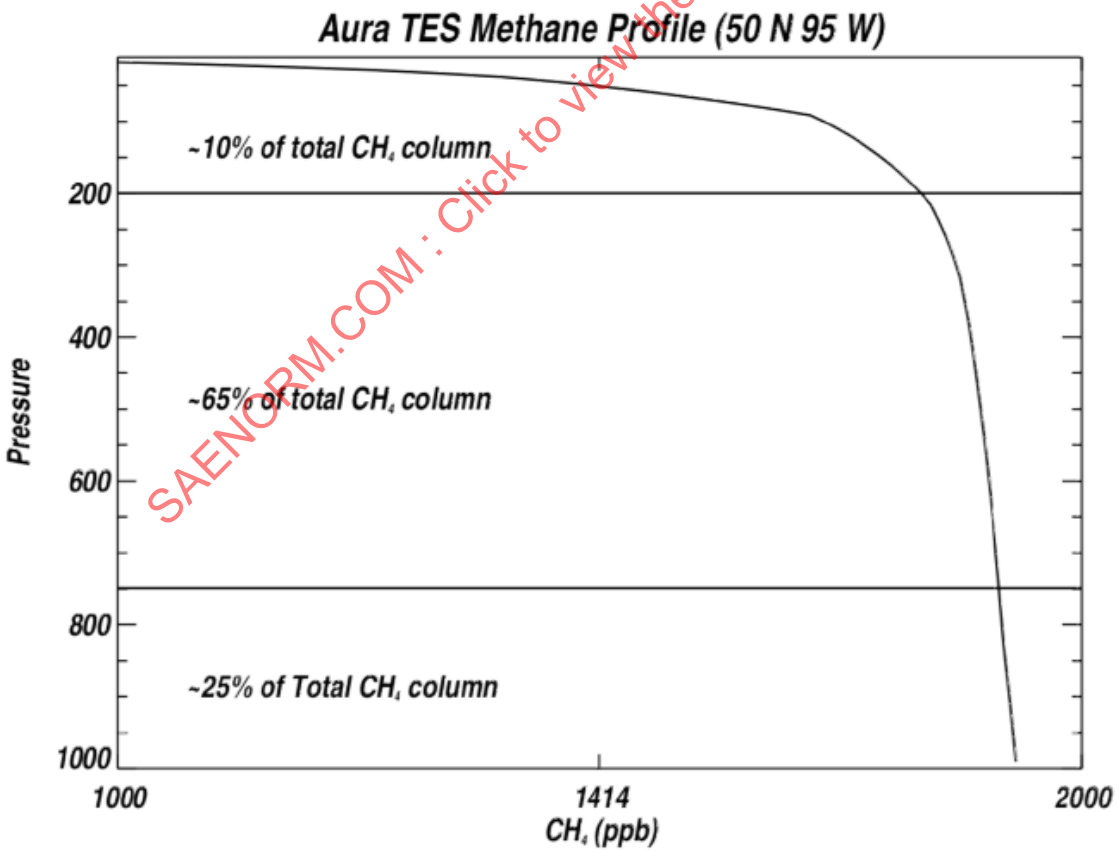

Figure 10 - Methane measured at atmospheric pressure
© Worden, J.R., Turner, A.J., Bloom, A.A., Kulawik, S.S., et al. [2015].
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Methylene chloride in the atmosphere is generally from anthropogenic sources (Umezawa et al. [2014]). Umezawa et al. [2014] studied variations of methylene chloride in the upper troposphere using civil aircraft from 2005 to 2011. Umezawa et al [2014], in their Figure 1(a), depict the relationships of CO and methylene chloride (CH_3Cl) in the CARIBIC passenger aircraft observatory.

This AIR discusses a selection of compounds that are representative of atmospheric contaminants which may be considered for accelerated life testing of ECS and fuel tank inerting system components. There are several reasons why it would not be practical to conduct accelerated life testing on ECS components using a large list of atmospheric contaminants. Reasons for selecting representative compounds include concerns with utilizing contaminants for which production is now restricted, such as some refrigerants and fluorocarbons, transient compounds such as acids and peroxides, and the safety of handling high concentrations of some of the potential contaminants.

Table 1 summarizes an extrapolation of approximate atmospheric contaminant levels at a range of altitudes.

Table 1 - Contaminant concentrations at various altitudes

Altitude, km Altitude, feet Absolute Pressure, hPa	**0 km 0k feet 1013 hPa**	**3.05 km 10k feet 697 hPa**	**9.14 km 30k feet 301 hPa**	**12.19 km 40k feet 187 hPa**	**15.24 km 50k feet 111 hPa**
Carbon Monoxide (Minschwaner et al [2007}, 60 degrees N)	10 ppbV 11 ug/m^3	10 ppbV 11 ug/m^3	15 ppbV 17 ug/m^3	150 ppbV 172 ug/m^3	150 ppbV 172 ug/m^3
CFC-11 (Figure 3, 60 degrees N)	0.17 ppbV 1.53 ug/m^3	0.17 ppbV 1.53 ug/m^3	0.17 ppbV 1.53 ug/m^3	0.17 ppbV 1.53 ug/m^3	0.17 ppbV 1.53 ug/m^3
Hydrogen Cyanide (Figure 8)	0.425 ppbV 0.45 ug/m^3	0.425 ppbV 0.45 ug/m^3	0.425 ppbV 0.45 ug/m^3	0.26 ppbV 0.28 ug/m^3	0.23 ppbV 0.24 ug/m^3
Hydrogen Fluoride (Figure 9, 60 degrees N)	<0.25 ppbV <0.21 ug/m^3	<0.25 ppbV <0.21 ug/m^3	<0.25 ppbV <0.21 ug/m^3	<0.25 ppbV 1<0.21 ug/m^3	0.25 ppbV 0.21 ug/m^3
Hydrogen Sulfide (Figure 4, 60 degrees N)	275 ppbV 384 ug/m^3	275 ppbV 384 ug/m^3	25 ppbV 35 ug/m^3	25 ppbV 35 ug/m^3	15 ppbV 21 ug/m^3
Methane (Figure 10, 50 degrees N)	1925 ppbV 1417 ug/m^3	1910 ppbV 1406 ug/m^3	1800 ppbV 1325 ug/m^3	1775 ppbV 1307 ug/m^3	1700 ppbV 1252 ug/m^3
Methanol (Figure 2, Atlantic, Pacific, Tropics)	1.5 ppbV 2 ug/m^3	1.5 ppbV 2 ug/m^3	1.5 ppbV 2 ug/m^3	1.5 ppbV 2 ug/m^3	Off scale
Methylene Chloride (Umezawa et al. [2014])	0.6 ppbV 2.1 ug/m^3	0.6 ppbV 2.1 ug/m^3	0.6 ppbV 2.1 ug/m^3	0.6 ppbV 2.1 ug/m^3	0.6 ppbV 2.1 ug/m^3
Methyl Hydroperoxide (INTEX-NA >3 km, Weinstein-Loyd et al. <3 km)	2 ppbV 3.9 ug/m^3	0.63 ppbV 1.2 ug/m^3	0.6 ppbV 1.2 ug/m^3	0.2 ppbV 0.4 ug/m^3	0.2 ppbV 0.4 ug/m^3
Nitrogen Oxides (NO_y) (Speidel et al, [2007])	2 ppbV	2 ppbV	2 ppbV	2 ppbV	2 ppbV
Ozone: Stratosphere, April (Figures 8 and 9); Troposphere, March to August, 60 degrees N Lat, Asia (Figure 7); AC 120-38	75 ppbV	75 ppbV	75 ppbV	600 ppbV 1.3 ppmV (AC 120-38)	600 ppbV 1.3 ppmV (AC 120-38)
Peroxyacetylnitrate (Figure 8)	0.23 ppbV 1.14 ug/m^3	0.23 ppbV 1.14 ug/m^3	0.23 ppbV 1.14 ug/m^3	0.125 ppbV 0.6 ug/m^3	0.007 ppbV 0.03 ug/m^3
Sulfur Dioxide (Speidel et al. [2007])	Not reported	0.16 ppbV 0.42 ug/m^3	0.08 ppbV 0.21 ug/m^3	0.04 ppbV 0.10 ug/m^3	Not reported

3.1.2 Ground-Level Contaminants

Ground-level chemical contaminants around airports are caused by air traffic, airfield equipment, motor vehicles operating in the area surrounding the airport, and other regional environmental activities. The final report for the Los Angeles Airport air quality and source apportionment study is one such example that provides concentration ranges for CO, NO_2, SO_2, PM2.5, select volatile and semivolatile compounds, elemental carbon, metals, ozone, and ultrafine particles. A future new SAE Standard for reducing ground contamination of aircraft ECS is being created.

On October 1, 2015, EPA reduced the 8-hour ozone NAAQS from 0.075 to 0.070 ppm based on extensive scientific evidence about the effects of ozone on public health and welfare (https://www3.epa.gov/region1/airquality/).Tropospheric ozone is formed by the interaction of sunlight, particularly ultraviolet light, with hydrocarbons and nitrogen oxides, which are emitted by automobile tailpipes and smokestacks. In urban areas, high ozone levels usually occur during warm summer months. Typically, ozone levels reach their peak in mid to late afternoon, after exhaust fumes from morning rush hour have had time to react in sunlight. A hot, sunny, still day is the perfect environment for the production of ozone. At the end of the day, as the sun starts to set, the production of ozone begins to subside. To form, ozone needs sunshine to fuel the chemical reaction (https://scied.ucar.edu/ozone-troposphere).

3.2 Sources of Liquid and Aerosol Contamination

3.2.1 Engine Lube Oil

Ingestion of aircraft exhaust may be one source of lube oil entry in the engine air system and hence into the bleed system and ECS (Cheng. [2013]; Schuchardt. [2019]). At temperatures above 200 °C, thermal decomposition products of oil or other substances may occur, depending on the specific characteristics of the fluid. Nagda, in ASHRAE TRP959 [2001], provides more detailed information on potential oil decomposition product constituents.

3.2.2 Compressor Section Compartment Cooling

Whenever possible, all combustible fluid lines, fire extinguishing equipment, and accessories are located in this area. If ram cooling or ventilating air is extracted from the engine inlet duct, then, during ground operation, a negative pressure is available at the engine inlet, tending to induce reverse flow from the compartment into the engine airstream. If an oil or fuel leak occurs, or if a compressor wash is performed without following the published procedure, some of the detergent can remain in the engine and get into the ECS. Under this condition, the contaminants are introduced into engine air, thence into the bleed air supply to the cabin.

3.2.3 Operating Environment

Airport environments contain unburned or partially burned hydrocarbons. These contaminants, which have been characterized by Cheng [2013], enter the ECS through APU, ground carts, or engine bleed.

3.2.4 Other Aerosol

Any of the fluids used in the aircraft systems or as cleaning agents can generate aerosol. These include lubricating oil, hydraulic fluids, fuel, and other contaminants found in the environment. Aircraft de-icing can expose the APU or main engines to ethylene glycol or propyylene glycol. Contaminants that are constituents of ambient air, unburned fuel, lubricants, and hydraulic fluids are found throughout the life support system in ground and flight tests (USAF. [2012]).

3.3 Particulate Contaminants

Dust particles in the atmosphere vary in size as well as quantity. Most particulates range in size from ultrafine particles that range is size from 10 to 200 nm to particles; and larger particles that range in size to about 250 µm. Particles smaller than this, ranging down to 10 nanometers, are now regulated by ICAO and National Authorities such as the U.S. EPA for aircraft engine particulate emissions.

Figure 11 (ASHRAE Handbook. [1977]) shows the size distribution of particles which make up atmospheric dust. Figure 12 depicts runway particle count distribution by size. These data were developed as a result of C-130 aircraft operations (Lockheed Georgia Company Report). Table 2 provides conversion from mesh size of the particles to microns (inches). Figure 12 indicates that over 50% of the particles are smaller than 250 µm in diameter. Fairlie et al. [2006], depict the size distribution of particles with respect to altitude in their Figure 5.

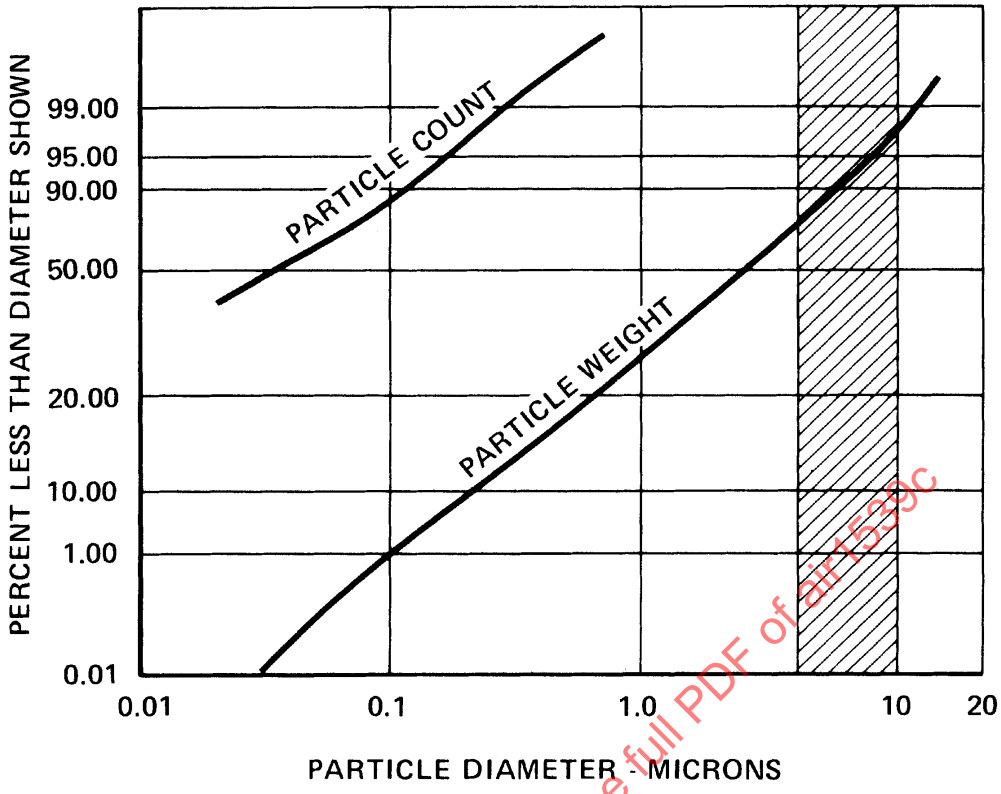

Figure 11 - Particle size distribution of atmospheric dust

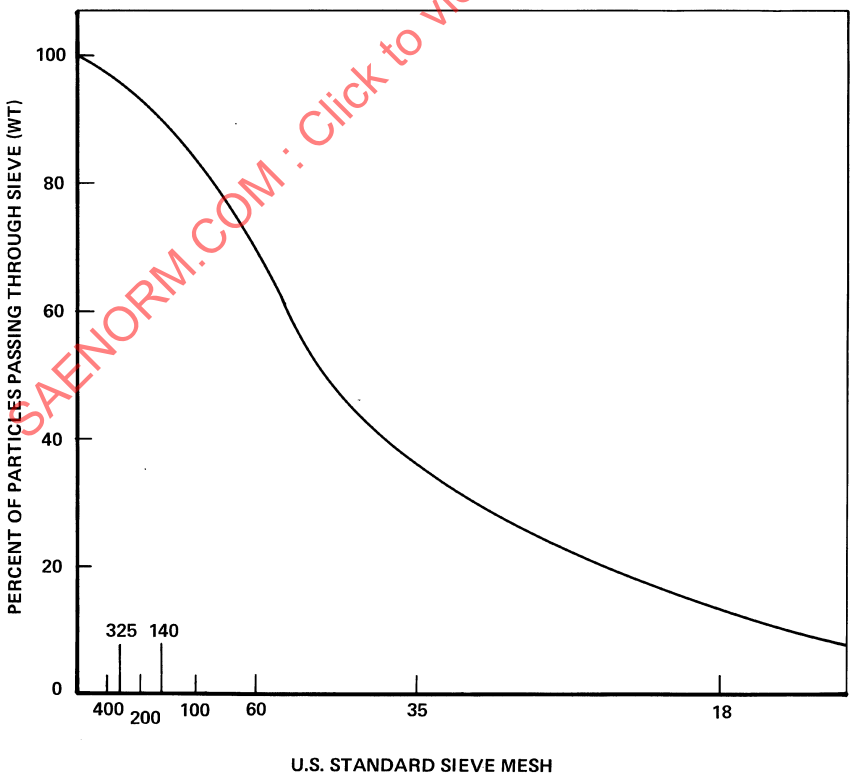

Figure 12 - Runway dirt particle size distribution

Table 2 - Particle size conversion table

Mesh	Inches	Microns	Nanometers
No. 18	0.0394	1000	1000000
No. 35	0.0197	500	500000
No. 60	0.0098	250	250000
No. 100	0.0059	149	149000
No. 140	0.0041	105	105000
No. 200	0.0029	74	74000
No. 325	0.0017	44	44000
No. 400	0.0015	37	37000

Particulate contaminants may consist of a number of different materials, depending on the operating environment, engine height above the runway, and inlet location in relation to the landing gear. Abrasive materials such as silica, metal chips, etc. are more likely to cause expansion turbine nozzle erosion, whereas carbon particles and lint will block filters and orifices. Examples of the size and types of contaminants for a low wing mounted engine operating from two different airports in Washington are shown in Tables 3 and 4 (Robins. [1969]). Particulates can enter the ECS through the engine, the APU, through ground carts, and—where auxiliary venting is provided—through the ram air inlets. All sources must be considered in developing contamination controls.

Table 3 - Size of particles contaminating valves and water separators

Particle Size (Microns)	<5	5-15	15-25	25-50	50-100	>100
Percentage (Weight)						
Valves	20-40	30-40	20-30	5-15	3	2
Water Separator Bags	0	60	20	15	5	<1

Table 4 - Contaminant constituents found in components

Material	Percentage by Weight	
	Valves	Water Separators
Carbonaceous	40-60	60
Copper	Trace	1
Aluminum, Steel	1-2	Trace
Siliceous	30-56	40
Plastic	Trace	0
Resinous	1-3	0
Fibers, Cellulose	1	Trace

3.3.1 Engine Bleed

This source ingests particulates during all ground operations, low-altitude climb, and descent. From 25 to 30% of the total will be ingested during the takeoff run, and 10 to 50% during approach and thrust reversal for a wing engine mounted close to the ground. The remainder will be ingested during ramp and taxi operations. For aft fuselage mounted engines, by far the largest amount of dirt enters during reverse thrust operation. See Fairlie et al. [2006] for the graphic relationship between particle size and altitude in one study. Aircraft observations (black crosses) from TRACE-P (top) and ACE-Asia (bottom) are compared with model results (red diamonds) sampled along the flight tracks.

The importance of engine bleed port design should be noted. In order to be in compliance with CS-E, the engine design should not cause particulate matter to be concentrated in air supplied to the bleed air system. Turbofan engines largely avoid this problem because most larger particulates are removed prior to entry into the compressor, and are routed into the fan duct. In turbojets or very low bypass ratio turbofans, if the extraction air is bled at the periphery of the compressor housing (OD bleed) without inertial separation designed into the off-take, the particulate concentration is much higher than the average concentration across the engine air inlet. Engines with provisions for bleed air extraction from the inside diameter (ID) of the compressor airflow passage (ID bleed) have shown much less bleed air contamination than air extracted from an improperly designed outside diameter (OD) port. However, ID bleed configurations can possess a higher risk of oil contamination from the lubrication system and should be sufficiently partitioned to minimize the likelihood of this type of contamination.

Contamination control through bleed port design becomes even more important as engine size and thrust increase. Engines in the 20000 kg thrust range have total inlet flows of up to 700 kg/s. This air flow rate may be sufficient to entrain larger particulates near engine inlets when they are mounted in close proximity to the ground, during takeoff. Design features should be incorporated to minimize entrainment.

3.3.2 APU and Ground Carts

Because these sources always operate in the contaminated airport environment, they may transmit a high percentage of the contamination to the system. Figure 13 shows the percentage of contamination due to ground operation with a ground cart or an APU having an inlet close to the ground. This is shown as a function of the ratio of hours of APU and ground operation to total flight hours. These predictions are based on aircraft operations from Boeing Field and Moses Lake (Robins. [1969]) and the relative contaminant populations for operations (Parker. [1970]; Robins, [1968]). Measurements made on a rear fuselage mounted airplane in airline service showed the contribution made by the APU to be small compared to that entering the ECS during main engine reverse thrust application. If APUs and ground carts extract bleed air from the compressor stage, the bleed ports should be designed to remove particulates as in the main engines.

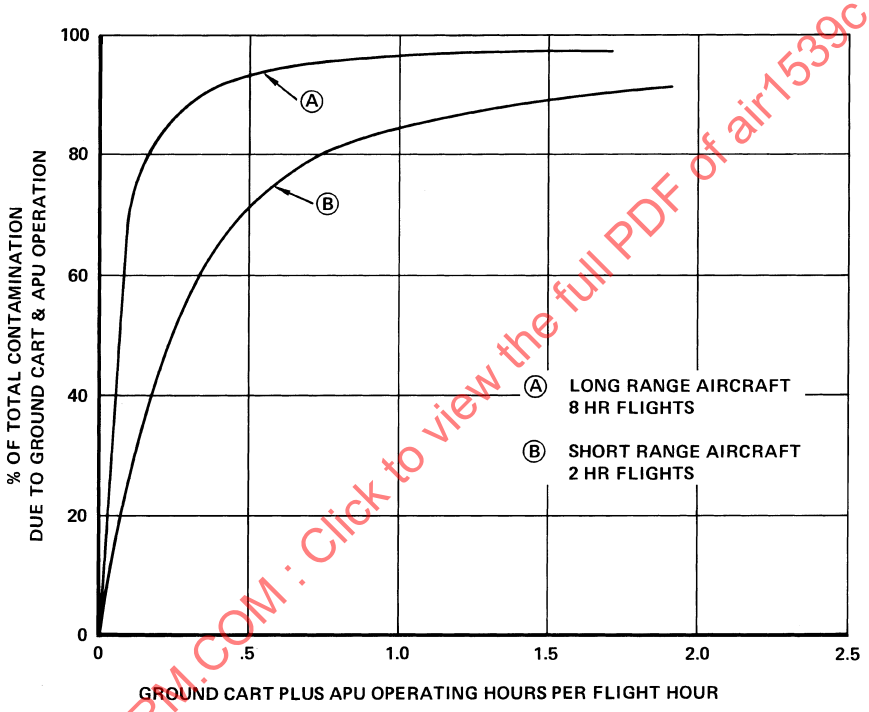

Figure 13 - Sources of contamination

3.3.3 Cabin Contaminants

Fibrous materials in the form of lint emanates from ground supply ducting, carpeting, seat materials, and passenger luggage and clothing. Fibrous material poses a serious cooling problem to cabin and avionics equipment.

Where smoking is permitted, tobacco tars are also contaminants which cannot be controlled at the source. Tars deposit onto cold surfaces and form a sticky residue, often combining with lint and particulates. The prohibition on smoking has greatly reduced contamination from tobacco tar deposits. More details on gaseouse and particulate contaminants are found in AIR7521, AIR4766, AIR4766/1, and AIR4766/2.

4. EFFECTS OF CONTAMINATION ON AIRCRAFT SYSTEMS

Atmospheric dust ingested by the engines, APUs, and high-pressure ground carts is the primary aircraft system source of contamination. It is possible that some particulates may be generated in the engines, particularly during initial run-ins; however, these are not considered serious contributors to overall contamination. There are, however, some internally generated contaminants, including carbon and oil vapors, that do affect components. Oil can be important in moderate quantities as a binder to solid particulate contaminants. These deposits can collect on filters and seals, in ACM bearings, and in heat exchangers, and can cause pneumatic component malfunction more rapidly than atmospheric contaminants.

The effect on equipment of particulates from pneumatic bleed air may be evident in any one or all of several different ways. The presence of contaminants can have a marked effect in: (1) degrading system performance, (2) requiring more frequent in-service maintenance, (3) increasing component removal rates, and (4) increasing shop overhaul rates.

4.1 Effects of Contamination on Equipment Performance and Life

Any equipment which is exposed to bleed air contaminants from the main engines or auxiliary engines should be evaluated as regards susceptibility to reduction in performance or life.

Performance degradation occurs when accumulations of contaminants or wear of components reduce the effectiveness of heat exchangers, turbomachinery, pneumatic or fluidic controls, and water separators. Some of the impacts are readily identifiable while others may be quite subtle. The latter increases the complexity of fault isolation procedures and are often difficult to prove.

Performance degradation accounts for increased cost to the user, even though it is not as visible as specific hardware failures, because it results in increased maintenance and overhaul costs. System installation factors can have a profound influence on the exposure of components to harmful contamination.

4.1.1 Pneumatic Valves and Regulators

In general, regulating devices are affected by the accumulation of dirt in critical orifices, seal rings, actuators, and small passages. The effects of this dirt are a shift in calibration, increases in leakage, sticky operation, and a failure to operate at all.

Critical pneumatic control circuits should include dirt removal devices to minimize the effects of contamination.

The choice between using relieving or non-relieving filters or inertial dirt separation feature can be made only after analyzing the effects of a plugged filter on system and aircraft performance.

4.1.2 Air Cycle Cooling Turbines

Air cycle cooling turbines are one of the major components entailing increased costs in environmental systems as a result of contamination present in bleed air. Particulate contaminants are extremely harmful—especially siliceous materials.

The principal problem resulting from operating of cooling turbines with dirt contaminated bleed air is erosion damage to the turbine nozzle. Secondary problems are damage to the turbine wheel and bearing failures due to dirt ingested into the oil sump. Particulate contaminants larger than approximately 10 µm in size, due to the mass of these particles, do not follow the airflow path at the nozzle exit, but instead strike the turbine wheel blade tips. The stagnation of particle movement between the turbine wheel inlet and the nozzle outlet generate wear or erosion of both turbine blades and nozzle outlets. When the particles are broken down to approximately 5 µm in size or smaller, they then pass through the turbine wheel and into the water separator and cabin air distribution system. Extensive laboratory test experience and field experience has demonstrated that the turbine wheel damage due to erosion is much less severe than the damage to the turbine nozzle.

In the first stages of nozzle erosion, there is very little loss of performance. Performance begins to seriously degrade when the throat area is enlarged as the wear progresses radially. Airflow through the turbine increases; however, total cooling decreases as turbine efficiency is reduced. In most systems, the system flow control valve will limit the flow although the increased nozzle area can increase the possible maximum turbine flow.

The rate of wear is a function of nozzle material, surface finish characteristics, as well as other variables, most particularly the airline route structure, the design of bleed ports, and particulate infiltration rate.

The turbine wheel erodes from the direct impingement of contaminated air from the nozzle. Erosion continues until the blade tip is worn to a sharp edge. Up to this point, no performance degradation occurs. With further erosion, the blade becomes shorter, and as the clearance between the blade and the nozzle ring increases, efficiency starts to drop off. Figure 14 depicts how cabin temperature and airflow typically increase with air cycle machine nozzle erosion.