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Ozone in High Altitude Aircraft

RATIONALE

This document has been determined to contain basic and stable technology which is not dynamic in nature.

STABILIZED NOTICE

This document has been declared "Stabilized" by the AC-9 Technical Committee and will no longer be subjected to periodic reviews for currency. Users are responsible for verifying references and continued suitability of technical requirements. Newer technology may exist.

INTRODUCTION

Since airplanes are pressurized and air-conditioned with air obtained from outside the aircraft, ozone present in the outside air enters the cabin. Ozone in the cabin air may cause discomfort and health effects, and destroys many materials. The discomfort and ill effects depends on concentration, exposure time and on an individual's sensitivity to ozone. "Ozone discomfort" appeared frequently and among a large population on B-747SP flights between New York and Tokyo during the 1976-1977 season. These flights operated at high latitudes and altitudes where ozone concentrations are high. This occurrence prompted the FAA to introduce regulations to limit cabin-air ozone concentrations.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

1. SCOPE:

The purpose of this report is to provide information on ozone, its effects, generally accepted ozone exposure limits (aviation and non-aviation), and methods of its control in high altitude aircraft. Sources of information are listed and referenced in the text.

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 exemption has been obtained.

2.1.1 FAA Publications: Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591.

FAA Advisory Circular AC 120-38 [10/10/80]: "Transport Category Airplanes Cabin Ozone Concentration", Initiated by AFO-260

FAA Advisory Circular AC 25-22, [3/14/00], "Certification of Transport Airplane Mechanical Systems", Initiated by ANM-110

FAA Advisory Circular AC 25-7A, [3/31/98], "Flight Test Guide for Certification of Transport Category Airplanes", Initiated by ANM-110

FAA AEQ –77-13- "Ozone Concentration By Latitude, Altitude, and Month, Near 80° West" (NTIS Accession Number ADA 046 956)

FAA Order 8110.4B, [April 24, 2000]- "Type Certification ", Initiated by AIR110

FAA-AEQ-77-13- "Ozone Concentration By Latitude, Altitude, and Month, Near 80° West" (NTIS Accession Number ADA 046 956)

FAA-AM-79-20 "Effects of ozone on exercising and sedentary adult men and women representative of the flight attendant population." E.A. Higgins, M.T. Lategola, J.M McKenzie, C.E. Melton, J.A Vaughn. (NTIS Accession Number ADA 080 045)

FAA-EQ-78-03- "Guidelines for Flight Planning During Periods of High Ozone Occurrence." (NTIS Accession No. 050 988)

U.S. Code of Federal Regulations, Title 14, § 121.578- "Cabin Ozone Concentration"

2.1.1 (Continued):

U.S. Code of Federal Regulations, Title 14, § 25.832- "Cabin Ozone Concentration"

U.S. Code of Federal Regulations, Title 14, Federal Aviation Regulation, Part 25- "Transport Category Airplanes"

U.S. Code of Federal Regulations, Title 14, Part 121- "Transport Category Airplanes"

U.S. Code of Federal Regulations, Title 14, Part 121- "Transport Category Airplanes" Amendment 154- "Airplane Cabin Ozone Concentration", Effective February 20, 1980

U.S. Code of Federal Regulations, Title 14, Part 121- Transport Category Airplanes Amendment 181- "Cabin Ozone Concentration", Effective January 31, 1983

U.S. Code of Federal Regulations, Title 14, Part 25- Transport Category Airplanes, Amendment 50, Airplane Cabin Ozone Concentration, Effective February 20, 1980

U.S. Code of Federal Regulations, Title 14, Part 25- Transport Category Airplanes, Amendment 56- "Cabin Ozone Concentration", Effective January 31, 1983

U.S. Code of Federal Regulations, Title 14, Part 25- Transport Category Airplanes, Amendment 89- "Allowable Carbon Dioxide Concentration in Transport Category Airplane Cabins"; Final Rule. Federal Register / Vol. 61 / No. 232 / Dec. 2, 1996/ Rules & Regulations

U.S. Code of Federal Regulations, Title 14, Part 25- Transport Category Airplanes, Amendment 94 - "Cabin Ozone Concentration", Effective February 23, 1988

2.1.2 Other U.S. Government Publications: Available from DODSSP, Superintendent of Documents, P.O. Box 371954, Pittsburgh, PA 15250-7954, USA.

Melton, C. E., [December 1989], "Airliner Cabin Ozone: an Updated Review", DOT/FAA/AM-89/13, Office of Aviation Medicine, Washington, DC 20581

NPRM 78-15- "Airplane Cabin Ozone Contamination." Federal Register (43 FR 46034), October 5, 1978

NPRM 81-15- "Cabin Ozone Concentration." Published in Federal Register Vol. 46. No. 225 November 23, 1981

U.S. Code of Federal Regulations, Title 21, §801.415, Food and Drug Administration, U.S. Dept of Health, Education and Welfare, "Maximum Acceptable Level of Ozone"

U.S. Code of Federal Regulations, Title 29, Occupational Safety and Health Administration, §1910.1000- "Air Contaminants"

2.1.2 (Continued):

U.S. Department of Transportation, DOT-P-15-89-5, [1989], "Airliner Cabin Environment"

U.S. Environmental Protection Agency, [1996], "Criteria for Ozone and Photochemical Oxidants", Integrative Summary of Ozone Health Effects, Vol. III, Pp. 9.1 to 9.39, , U.S. Government Printing Office 750-001/41010

U.S. Environmental Protection Agency, [Nov 29, 1996], Office of Air & Radiation, Office of Air Quality Planning & Standards, Clean Air Advisory Committee Fact Sheet: "Health And Environmental Effects of Ground-Level Ozone", http://134.67.104.12/naaqspro/o3fact.htm

2.1.3 JAA Publications: Available from Printing and Publication Services, Civil Aviation Authority, Greville House, 37 Gratton Road, Cheltenham GL50, 2BN, England.

JAR 25- Large Airplanes, NPA 25D-285- "Allowable Carbon Dioxide in Airplane Cabins and Cabin Ozone Concentrations", May 2000

2.2 Other Applicable References:

American Society for Testing and Materials Standard D-6399 [1999], "Standard Guide for Selecting Instruments and Methods for Measuring Air Quality in Aircraft Cabins"

American Society of Heating Refrigeration and Air-conditioning Engineers, Standard 62-1989, addendum 62a-1990, Table 3

Benson, S. W. and Axworthy, A. E., Jr., [June 1957], "Mechanism of the Gas Phase Thermal Decomposition of Ozone", Journal of Chemical Physics, 26: 1718

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Boberg, J. E. and Levine, M., [1962], "Catalytic Filtration of Ozone in Airborne Application", ASME Transactions, series B, Journal of Engineering for Industry, 84: 42, 1962 or ASME paper no. 61-AV2, Los Angeles, Ca. 1961

Canadian Aviation Occupational Safety and Health, [1994], "Règlement concernant la sécurité et la santé au travail." Code Canadien du travail-Partie 2. Groupe Communication Canada - Edition. Ottawa, Canada, K1A 059, L31-85/1994F

Code du travail, France, [1999]: Journal Officiel de la République Française, 26 rue d'Essex, 75727 Paris Cedex 15, ISBN 2-11-0736-18-6, ISSN 0767-4538

Cone, James E., [1985], "Cabin Air Quality", Occupational Health Clinic, San Francisco, 97 pp18
Conseil des Communautés Européennes, [9/21/1992], Directive 92/72/CEE- "Ozone"

2.2 (Continued):

FAA Letter 9-112-001, From Mr. Ronald T. Wojnar, Manager Transport Airplane Directorate Aircraft Certification Service to Mr. Alankar Gupta, Chairman, SAE AC-9 Technical Committee, May 18, 1999

Heusden, S. Van and Mans, L.G.J., [September 1978], "Alternating Measurement of Ambient Cabin Ozone Concentration in Commercial Jet Aircraft", Aviation, Space and Environmental Medicine

International Organization for Standardization, ISO 13964, [Aug. 1, 1998], "Air Quality-Determination of Ozone in Ambient Air- Ultraviolet Photometric Method", First Edition, International Organization for Standardization, Case Postale 56, Geneva, Switzerland CH-1211, 41-22-734-0150, 41-22-734-10-79

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MOZAIC/MOZCAB, [1994], "Measurements of Ozone on Airbus In-Service Aircraft", Airbus Industrie, AI/TD –D 820 00064, 23 pp

Nastrom, Gregory D. & al., [April 1980], "Measurements of Cabin and Ambient Ozone on B-747 Airplanes". J. Aircraft, Vol. 17, No. 4, GASP/NASA

U.K. EH 40/96, Occupational Exposure Limits, (ISBN 0 7176 1021 7)

Waters, Martha, [May 1998], "Air Quality Measurements in Aircraft Cabins." Abstracts of Aerospace Medical Association Scientific, sessions, 69th Annual Meeting, Seattle, Aerospace Medical Association, 320 S. Henry Street, Alexandria, VA 22314-3579

World Health Organization, [1979], "Photochemical Oxydants, Environmental Health Criteria, N° 7."

World Health Organization, [1987], "Air Quality Guidelines for Europe", WHO Regional Publications, European Series

2.3 Definitions:

CERTIFICATION BASIS - Title 14 CFR Part 25 regulations that apply to an airplane.

NOTE: FAA Order 8110.4B, Chapter 2, Par 2-10d, provides methodology to develop the certification basis of changed products.

FL - Flight Level - FL. airplane operating altitude in hundreds of feet (FL 300 = 30,000 ft).

FS - Flight Segment - Nonstop flight time between two airports (14CFR §121.578)

Nm^3 - Normo cubic meter at 760 mm Hg and 20 °C

PEL - Permissible Exposure Limit - concentration that shall be achieved by a combination of engineering controls, work practices and personal protective equipment. (Title 29, CFR§1910.1000)

R - Ozone Retention factor - Ratio of Cabin-air to Outside air ozone concentrations.

SLE - Sea Level Equivalent - Partial pressure equivalent to that which the contaminant gas exerts at sea- level at the specified temperature. The FAA has selected a temperature of 25 °C.

STEL - Short Term Exposure Limit - employee's 15 minute time weighted average exposure which shall not be exceeded during a work day. (Title 29, CFR §1910.1000)

STRATOSPHERE - Layer of air above the tropopause in which the temperature increases with increase in altitude. In the U.S. Standard Atmosphere the Stratosphere is assumed to extend from 25,000 to 47,550 m (82,000 to 156,000 ft). The altitude of the Stratosphere changes with latitude and season.

TROPOPAUSE - Layer of air sandwiched between the troposphere and the stratosphere. In this layer the temperature is essentially constant. In the U.S. Standard Atmosphere the tropopause is assumed to extend from 11,200 m (36,700 ft) to approximately 25,000 m (82,000 ft). The temperature in the tropopause is assumed to be -57 °C (-70 °F). The extent and the temperature of the tropopause changes with latitude and season.

TROPOSPHERE - A thin layer of air around the earth in which the temperature decreases with increase in altitude. In the U.S. Standard Atmosphere the troposphere is assumed to extend from sea-level to 11,200 m (36,700 ft). The temperature is assumed to change (lapse rate) at the rate of -6 °C/1000 m (-3.655 °F/ 1000 ft). The extent of the troposphere changes with latitude andseasons.

TWA - Time Weighted Average - Employee’s average exposure in 8-hour work shift of a 40-hour work week that shall not be exceeded. (Title 29, CFR §1910.1000).

NOTE: 14 CFR § 25.832 and 14 CFR § 121.578 use shorter time duration to determine TWA.

3. OZONE CONCENTRATION LIMITS:

Exposure concentration and exposure duration are important factors in determining the effect of ozone on humans. Therefore, standards, regulations and guidelines usually stipulate acceptable long term and short duration threshold limit concentrations.

3.1 Atmospheric Ozone Concentrations:

"Ozone" is derived from the Greek word "ozein" meaning to smell. In the lower atmosphere (troposphere[1]) ozone forms when lightning passes through the air. It is readily perceptible after a lightning storm by its pungent aroma and irritating effects. Ozone forms by photo-chemical reactions with airborne contaminants such as nitrogen oxides and hydrocarbons. It is also a by-product of industrial processes. Ozone is unstable; it decomposes and forms oxygen. It exists in parts per billion (ppb) near ground level. Its concentration goes up during pollution conditions. In the upper atmosphere (stratosphere 1) sunlight, continuously forms and destroys ozone. The stratospheric ozone layer thickness and concentrations vary continuously at mid and high latitudes.

In the upper atmosphere (stratosphere) short wavelength Ultra-Violet A light (less than 2450 angstrom), splits oxygen molecules into atomic oxygen. The oxygen atoms react with oxygen molecules and form ozone molecules. The longer wavelength Ultra-Violet B light (greater than 2450 angstrom), reacts with ozone molecules and splits them into oxygen molecules and oxygen atoms. Two oxygen atoms combine together to form an oxygen molecule. The formation and destruction of ozone occurs continuously. Also, chemical reactions in the stratosphere destroy ozone. Stratospheric ozone provides protection from solar radiation harmful to humans, fauna and flora.

TABLE 1

Ozone Formation		Ozone Destruction
O_2	$\Rightarrow O + O$	$O_3 \Rightarrow O_2 + O$
$O + O_2$	$\Rightarrow O_3$	$O + O \Rightarrow O_2$
(UV-A rays)		(UV-B rays)

The stratospheric ozone layer varies continuously. The peak concentrations and their altitudes change with location, season, and solar activity (see Figure 1). The concentrations are higher during spring and at high latitudes. In the northern hemisphere the peak concentration occurs between 21,300 and 30,500 m (70,000 to 100,000 ft) altitude. Above and below the peak concentration altitudes the concentrations decrease. Figure 1, which is based on data from FAA-EQ-78-03, shows the ozone concentrations that are not exceeded 84% of the time in North America for altitudes up to 13,700 m (45,000 ft). Detailed data for the southern hemisphere is not available. In the southern hemisphere seasonal levels are generally considered to be similar to the northern hemisphere seasonal levels, although with a 6 months interposition delay. Also, it is believed that the ozone concentrations at intermediate altitudes and latitudes can be interpolated. FAA AEQ –77-13 provides data at high (80°N) latitude.

1. See 2.3 for definitions.

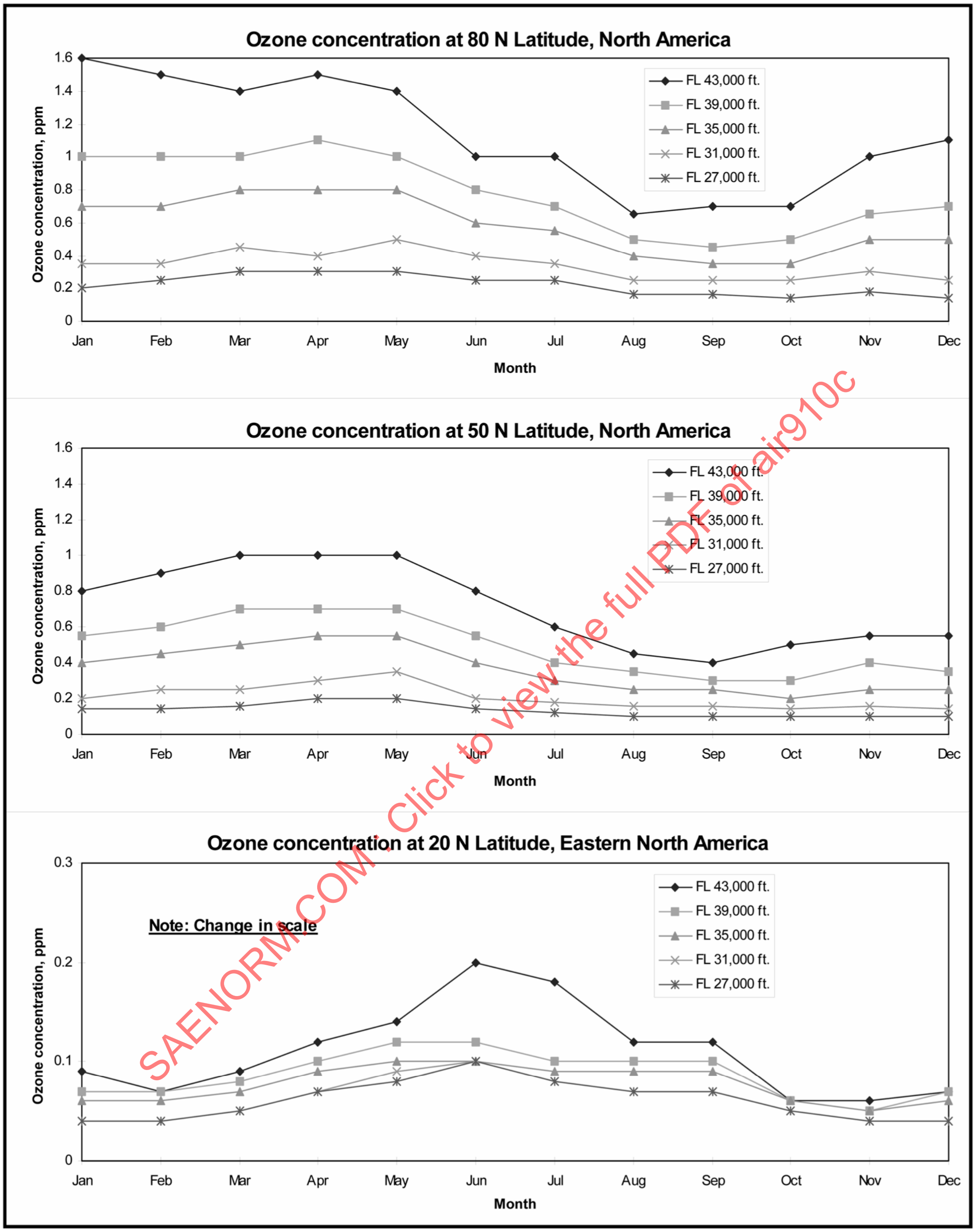

FIGURE 1 - 84% Confidence Level Outside Air Ozone Concentrations, North America
(NOTE: 0.1 ppm O_3 = 200 µg/Nm^3O_3)

3.1 (Continued):

Significant variations of outside air ozone concentrations are experienced during north to south (or south to north) flights when an airplane traverses different latitudes. For example, an airplane departing from Mexico City, Mexico (20°N) to Fairbanks, Alaska (65°N) with a cruise altitude of 13,100 m (43,000 ft) experiences approximately 1000% increase in outside air ozone concentrations (see Figure 1). Also, the concentration exposure increases with flight time as the altitudes and latitudes increase. On the return flight from Fairbanks, Alaska (65°N) to Mexico City, Mexico (20°N) with a cruise altitude of 13,100 m (43,000 ft) the concentration variation is substantially less; the outside ozone concentrations decrease (at constant altitude) as the airplane travels to lower latitudes. In short, the mean exposure during south to north flight is different than the exposure during north to south flight. Significant variations of in-cabin ozone concentrations are also observed within a short time, half an hour, or less. Figure 2 and Table 2 show data observed during service. This emphasizes the need for selection of critical flight conditions for determination of the Maximum (or Peak), and short integration time for Time Weighted Average (TWA[2]) concentration calculations.

Significant ozone concentrations also occur at or near ground level. They occur due to chemical reactions between airborne contaminants such as nitrogen oxides, hydrocarbons, and volatile organic compounds (VOCs). EPA "Criteria for Ozone and Photochemical Oxidants" reports the measured maximum ozone concentration in Los Angeles as 0.9 parts per million by volume (ppmv). Numerous occurrences of 0.5 ppm are reported in literature at several locations. A global increase of 1.4% ozone per year, at or near ground level, has been observed and correlated to increased air pollution. (Reference Airbus Industries Report AI/TD – D 820 00064/94).

3.2 Cabin-Air Ozone Concentration:

The ozone concentration in the cabin is lower than the outside air concentration. The ratio, incabin ozone concentration/outside air ozone concentration, is known as the Retention Factor or Retention Ratio, R. Retention Factor depends on a number of variables: passenger load factor, interior materials, ratio of recirculated to outside air, incoming air ozone concentration, interior surface to volume ratio, air conditioning system design and operational parameters. In general, the retention factor decreases with increasing operating temperature, increased ratio of recirculated air/outside air, and increased compartment occupancy. It must be determined for the critical set of operating conditions at ambient ozone concentration levels typical of those that may exist in flight, whether the aircraft is equipped with ozone converters or not.

Retention factors have been evaluated for several airplanes. The FAA accepts a default value of 0.7 for the ozone retention ratio when demonstrating compliance to both 14 CFR § 25.832 and 14 CFR § 121.578 (Reference Final Rule Preamble, Amdt Nos. 25-56 and 121-181). If a retention value of less than 0.7 is proposed, the FAA will require certification testing to validate the proposed retention level. (Reference NPRM 81-15). See also Section 7.

2. See 2.3 for definitions.

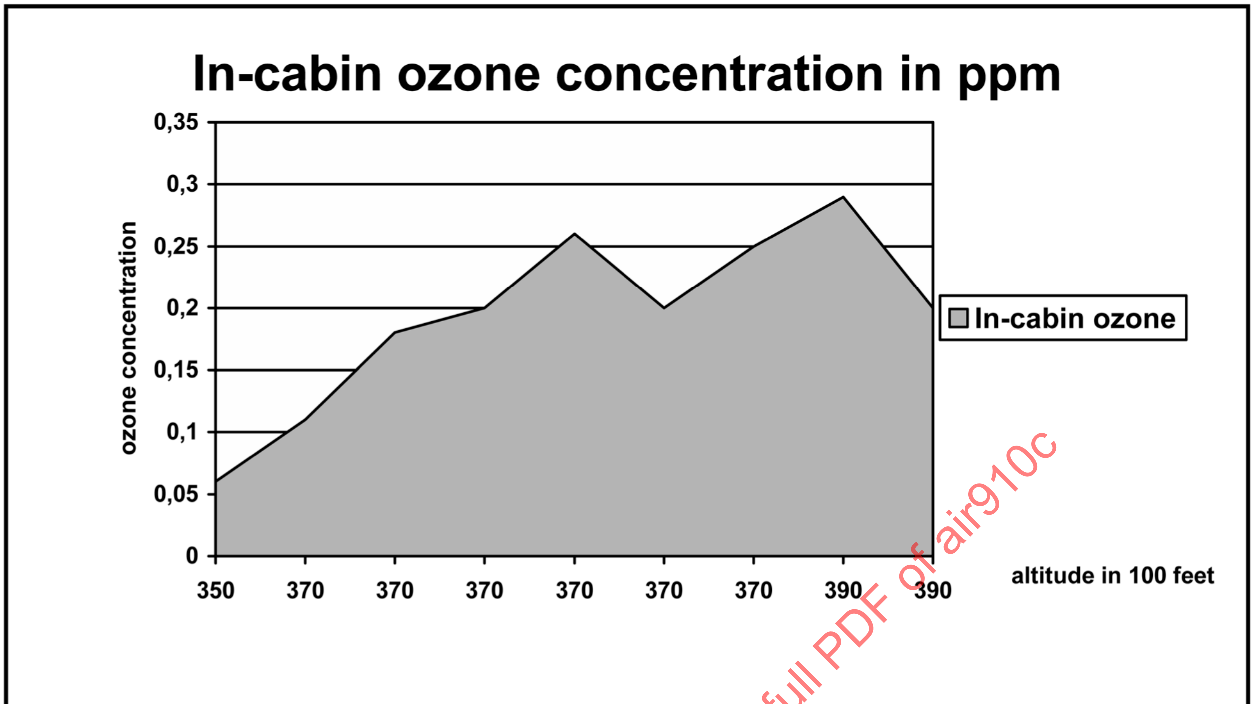

FIGURE 2 - Example of Variations of In-Flight Deck Ozone Concentrations With Altitude
2 packs on. February 1987. Route North America to Europe. No ozone converted fitted.

TABLE 2 - Example of Variations of In-Flight Deck Ozone Concentrations With Time, Altitude, and Latitude
2 packs on. February 1987. Route North America to Europe. No ozone converted fitted.

In-cabin Ozone ($\mu g/Nm^3$)	In-cabin Ozone (ppm)	Time, Hrs-Min	Altitude (m)	Flight Level	Latitude N. (degres)
120	0.060	09 H 33	10,670	350	53.6
220	0.110	10 H 33	11,280	370	57.0
360	0.18	11 H 24	11,280	370	59.0
400	0.20	12 H 05	11,280	370	59.0
520	0.26	12 H 50	11,280	370	58.0
400	0. 20	13 H 35	11,280	370	56.0
500	0. 25	14 H 05	11,280	370	54.4
580	0. 29	14 H 30	11,890	390	52.6
400	0. 20	15 H 15	11,890	390	49.3

3.3 Ozone Regulations and Guidelines:

3.3.1 Non-Aviation:

3.3.1.1 Guidelines: In 1996 the United States Environmental Protection Agency proposed 0.12 ppm 1 hour Time Weighted Average (TWA) and 0.08 ppm 8 hours TWA for ambient air quality. (Reference EPA "Criteria for Ozone and Photochemical Oxidants".). In year 2000, the American Conference for Governmental and Industrial Hygienists proposed set the 8 hour TWA at 0.05 ppm. The United Nations World Health Organization (WHO) recommended 0.1 ppm maximum in 1979. (Reference WHO, Photochemical Oxydants, Environmental Health Criteria, N°7.). European Air Quality Guidelines proposed 0.05 to 0.06 ppm 8 hours TWA and 0.076 to 0.1 ppm 1 hour TWA in 1989. (Reference WHO, "Air Quality Guidelines for Europe"). A 1992 European Directive, Conseil des Communautés Européennes, Directive 92/72/CEE, proposed 0.056 ppm (110 $\mu g/m^3$), as the health protection level for an 8 hour TWA; 0.0918 ppm (180 $\mu g/Nm^3$ (3)) for 1 hour TWA and to alert the public when the level for 1 hour TWA exceeds 0.184 ppm (360 $\mu g/Nm^3$).

U.S. EPA fact sheet (Reference EPA "Criteria for Ozone and Photochemical Oxidants") released in 1996 comments on the National Ambient Air Quality Standard (NAAQS). The fact sheet states that "many of the new health studies show that health effects occur at levels lower that the current standard - 0.12 ppm 1 hour TWA -." In addition, the Clean Air Scientific Advisory Committee in "Health And Environmental Effects of Ground-Level Ozone" concluded that the existing standard - 0.12 ppm 1 hour TWA - "contains little, if any, margin of safety."

3.3.1.2 Occupational Exposure Limits: Occupational exposure limits mandatory in the U.S., UK and France to safeguard worker health are listed in Table 3.

TABLE 3 - Occupational Exposure Limits

Regulatory Agency	Short Term Exposure Limit (STEL)	Long Term Exposure
U. S. (Occupational Safety and Health Administration) Title 29 CFR §1910.1000	0.3 ppm STEL* - 15 minute	0.1 ppm TWA* 0.1 ppm PEL*
U. K. EH 40/96, Occupational Exposure Limits	0.2 ppm (15 minutes)	
France (Occupational Exposure), Code du travail	0.2 ppm (limit)	

* See paragraph 2.3 for definitions.

3.3.1.3 Standards: American Society of Heating Refrigeration and Air-conditioning Engineers (ASHRAE) recommends 0.05 ppm (8 hours TWA). (Reference ASHRAE, Standard 62-1989, addendum 62a-1990, Table 3). U.S. Dept of Health, Code of Federal Regulations, Title 21, §801.415 provides a long term exposure limit of 0.05 ppm continuous.

3.3.2 Aviation:

3.3.2.1 Federal Aviation Regulation: 14 CFR § 25.832 Amendment 25-50 first imposed limits on cabin ozone concentrations to aircraft certification. 14 CFR § 121.578 Amendment 121-154 first imposed cabin air ozone concentration limits on in-service airplanes. This regulation applies to U.S. operators. These regulations were introduced in 1980 and have been updated several times. FAA regulations are periodically updated and the Code of Federal Regulations Part 25 and Part 121 should be checked for the latest amendment.

3.3.2.2 Joint Airworthiness Regulations (JAR): Joint Airworthiness Authority (JAA) currently prescribes no ozone concentration limits for certification of transport category airplanes. JAA has released a Notice for Proposed Amendment (NPA) 25D-285. It has the limits that were previously identified in 14 CFR § 25.832, Amendment 25-56. The JAA NPA has an error, 0.1 ppm printed as 0.01 ppm. This error existed in 14 CFR § 25.832 Amendment 25-56. The FAA corrected the error by Amendment 25-94.

3.3.2.3 Canadian Aviation Occupational Safety and Health (CAOSH): Guidelines released by the American Conference of Governmental and Industrial Hygienists (ACGIH) are used under CAOSH. (Reference CAOSH, [1994], Code Canadien du travail-Partie 2)

3.4 Biological Effects:

Over 1000 scientific research papers on health effects of ozone have been published in the past decade. Symptomatology is a function of ozone concentrations, duration of exposure, and exercise level. Inflammation of lung tissue and mucoses is a recognized effect of ozone. It is a powerful oxidant and its effects, both acute and chronic, on the respiratory tract and tissues are documented. Health and biological effects have been observed at 0.05 ppm (100 µg/Nm^3). The effects of ozone at a given concentration may vary over a wide range, from one individual to another.

The information in 3.4.1 through 3.4.3 is summarized from a 1996 EPA Fact Sheet titled "Criteria for Ozone and Photochemical Oxidants". For a more complete discussion of these factors refer to the EPA pamphlet.

3.4.1 Lungs: When inhaled, ozone can:

a. cause acute respiratory problems;
b. aggravate asthma, or cause increased asthma attacks;
c. cause temporary decreases in the lung capacity of 15 to 20% in healthy adults, even those moderately exercising;
d. cause inflammation of lung tissue;
e. lead to hospital admissions and emergency room visits (10 to 20% of all summertime respiratory related hospital visits in the northeastern U.S. are associated with ozone pollution);
f. increase susceptibility to respiratory illnesses, including bronchitis and pneumonia, by immune system defenses impairment;
g. children and asthmatics, or persons with reduced respiratory functions are more at risk .

Other documented effects include pulmonary edema, dyspnea (difficult breathing), rapid shallow breathing, pain on inspiration, thoracic oppression, cough, increased small airways resistance, reduced Forced Expiratory Volume (FEV), reduced bactericidal pulmonary defense capacity, fibrosis, and emphysema. (Reference Lippman, [1993])

Physical activity accentuates ozone effects. The FAA recognized this characteristic and conducted tests at 6000 ft altitude to develop the peak and TWA concentration limits. (Reference FAA-AM-79-20)

3.4.2 Blood: Alterations in circulating red blood cells and in various components of the serum have been observed.

3.4.3 Other Symptoms: Some other effects of ozone are headache, dryness of mouth, nose and throat, impairment of smell (anaesthesic effects), fatigue, insomnia, tachychardia, or altered mental concentration. The effects are accentuated with physical activity, which affects volumetric inhalation and respiration rate. (Reference EPA "Criteria for Ozone and Photochemical Oxidants") Flight crew report effects similar to those that result from exposure to ozone exposure at a far greater frequency than do the passengers who are sedentary. According to that same EPA report over 3000 reports have been published on the health and ecological effects of ozone, monitoring and ambient air quality levels since late 1980.

3.5 Ozone Effects on Materials:

Ozone concentrations of approximately 0.1 ppm (200 μg/Nm^3) cause serious deterioration of rubber. Synthetic rubber is less vulnerable to ozone. Some specially formulated elastomers are insensitive to ozone exposure.

4. CABIN-AIR OZONE CONCENTRATIONS – MEASURED IN-SERVICE:

Most jet transports cruise at altitudes where ambient air ozone levels can be higher than the cabin-air concentration limits imposed by the Federal Aviation Regulations. Cabin-air ozone concentrations have been measured by several investigators. (Reference DOT-P-15-89-5, [1989], Nastrom, [April 1980] and Melton, [1989]) Test data indicates ozone concentrations inside the flight deck are usually higher than in the passenger cabin. This is because the flight deck ventilation rate, per unit compartment volume or per occupant, is substantially higher than in the cabin. The high flow rate of up to 70 liters per second (lps), (150 cfm) per flight-deck crew member is provided to remove heat generated by electrical/electronic equipment and the solar heat that enters the flight deck through transparent surfaces.

The ozone concentrations are generally lower in the tourist section than in business and first class. This results from lower ventilation flow per passenger in the tourist section than in business or first class by virtue of the higher occupancy per unit floor area. Typically, airplanes are designed to provide a constant flow rate per unit length of the passenger compartment.

4.1 Parameters That Influence Cabin-Air Ozone Concentration:

The cabin air ozone depends on a number of parameters: aircraft type, engine, equipment, and operation. This causes large variations in measured values between flights. Table 4 lists the parameters and the factors that influence the parameters.

TABLE 4 - Parameters That Influence In-Cabin Ozone Concentration

Parameter	Factors That Influence In-Cabin Ozone Concentration
Aircraft Type	Number of air-conditioning packs, engine type, outside airflow, recirculation ratio, total ventilation flow, etc…
Equipment Design	Type of air-conditioning system, materials of constructions, cabin materials, filters or ozone converters, etc…
Operation	Flight path, altitude, latitude, seasons, concentration level at ground, solar activity, wind velocity and direction. Air-conditioning system operating modes. Passenger load factor and distribution. Equipment condition (ozone filter or converter), equipment failures (pack, fans, etc…)

4.2 Observed Cabin-Air Ozone Concentrations- Airplanes Without Ozone Filter (or Converter):

Illinois Institute of Technology (IIT) Research Institute measured ozone concentration in aircraft cabins during 285 commercial jet flights in 1962/1963 under the sponsorship of the FAA. (Reference Melton, [1989]) A microcoulomb ozone sensor that utilizes the oxidation/reduction of potassium iodide was used. The data was recorded on short (e.g., Chicago to New York), medium (e.g., Chicago to San Francisco), and long (e.g., intercontinental, London to San Francisco) flights. On a domestic flight ozone concentration greater than 0.2 ppmv (400 µg/Nm^3) was encountered for 140 minutes. On a northern flight concentrations in the range of 0.2 and 0.3 ppmv (400 to 600 µg/Nm^3) were observed for 4 hours. On a flight from Anchorage to New York, during the spring season, ozone concentrations in the range of 0.35 to 0.4 ppmv (700 to 800 µg/Nm^3) lasted for 20 minutes.

On round trip flights between Amsterdam and Toronto, ozone concentrations in the range of 0.15 to 0.3 ppm (300 to 600 µg/Nm^3) were recorded on approximately 70% of the flights in 1978. (Reference Heusden and Mans, [September 1978]) Cabin ozone concentration was measured on 14 flights over the polar region. The investigators used a Comhyr ECC meter, 5% accuracy. Ozone concentration in excess of 1 ppm was measured once. Concentrations between 0.1 and 0.7 ppm (200 to 1400 µg/Nm^3) were observed several times. High concentrations were recorded during the spring season and while flying within the jetstream. (Reference Bishof, [1973])

Cabin ozone concentrations were also measured in the NASA Global Sampling Program. (Nastrom & al., [April 1980]) The measurements were made on 196 flights in 1980. The cabin air at 1.5 m (4.5 ft) above the floor, in the forward compartment on the outside wall of the circular staircase of the Boeing 747, was analyzed using an ultraviolet spectrophotometer.

The National Institute of Occupational Safety and Health (NIOSH), in a joint program with the FAA, observed one-minute average concentrations ranging from 0.01 to 0.47 ppm (50 to 2 350 µg/Nm^3). (Reference Waters, [1998])

All test reports indicate that cabin air ozone concentration is always lower than outside air concentrations. This is due to the following processes that cause ozone decomposition and or dilution:

a. Decomposition due to temperature rise of 175 to 200 °C (350 to 400 °F) in the engine compressors, scrubbing with materials of the air supply and air conditioning systems, and the compression process (temperature rise) in the air cycle machine. The Environmental Control System (ECS) uses engine bleed air as the air source.

b. Dilution with filtered cabin air in the distribution system. Cabin air, used to augment effective ventilation rate, has lower ozone content.

c. Decomposition due to scrubbing with materials in the cabin and reaction with cabin-air contaminants. Ozone is a strong oxidizer.

4.2 (Continued):

d. The ozone retention factor, 0.30 to 0.70 range, depends on several variables: supply air ozone concentration and temperature, ECS design, passenger load factor, outside to recirculated cabin air ratio, materials, etc.

Table 5 summarizes the observations of investigators. The intent of the table is to present what has been observed to occur in-service on airplanes without an ozone filter or converter.

TABLE 5 - Cabin-Air Ozone Concentrations Recorded by Investigators
(Airplanes Without an Ozone Filter or Converter)

(Nm^3 refers to Normo cubic meters (Sea level, 20 °C)

Mean Concentration	Peak Concentration	Aircraft Type & No. of flight (% of total flights)	Source
>0.1 ppm (200 µg/Nm^3)		B-747 111 (58% of 196 flights)	Nastrom, [April 1980]
	>0.3 ppm (600 µg/Nm^3)	B-747 118 (60% of 196 flights)	
	>0.5 ppm (1000 µg/Nm^3)	B-747 45 (23% of 196 flights)	
>0.1 ppm		14 flights (100% of Copenhagen/Seattle flights)	Cone, [1985]
>0.1 ppm	0.7 ppm (1400 µg/Nm^3)	143 flights (50% of 286 studied flights) (Domestic+Hawaii+Alaska)	Melton, [1989]
	0.47 ppm (940 µg/Nm^3)	53 US domestic flights	Waters, [1998]

4.3 Observed Ozone Concentrations: Airplanes With Ozone Filter (or Converter):

Few investigations of cabin ozone concentration have been conducted on airplanes with ozone converters. In 1987 Air Canada conducted an investigation on its fleet, comparing ozone levels on aircraft fitted and not fitted with ozone converters (see Figure 2 and Table 2). MOZAIC is a European program measuring outside air ozone concentrations on two A-340 operated by two European airlines. Available data indicate that in-cabin ozone levels are generally less than 0.05 ppm (10 µg/Nm^3) and often less than 0.01 ppm (20 µg/Nm^3) on airplanes that had properly functioning ozone (catalytic) converters. (Reference MOZAIC/MOZCAB, [1994])

A 1997 survey indicated that about 50% of the world fleet of wide body aircraft is equipped with ozone converters. Differences in ozone converter equipment can be attributed to some of the following reasons:

a. 14 CFR § 25.832 and 14 CFR § 121.578 are U.S. Aviation Requirements;

b. The airplanes were certified prior to the effective date of 14 CFR § 25.832;

c. FAA has accepted the original certification basis for modified (later models) products. (Reference FAA Order 8110.4B, Chapter 2, Par 2-10d);

d. The airplanes operate in an altitude controlled environment wherein compliance can be demonstrated without the use of converters.

Ozone converters are essentially non-existent on narrow-body commercial airplanes, which generally fly short distances and cruise at lower altitudes. The former makes them exempt from the TWA concentration limits applicable when the flight segment is equal or greater than 4 hours. The latter exposes them to lower levels of outside ozone concentration. Retrofit of ozone converters to narrow body commercial aircraft is possible with minor ECS modification due to their small envelope. Also, wide-body freighters (all cargo aircraft) generally do not have ozone converters; they are exempted from the requirements by 14 CFR § 121.578(e)(1).

Ozone converters have been common in some private jet aircraft for about the last decade. Many current high performance private jet airplanes are capable of flight at the altitudes, latitudes and durations where high atmospheric ozone concentrations are present.

5. OZONE MEASUREMENT:

Since the 1960s, several ozone measurement methods have been used. Reliability, accuracy, repeatability, sensitivity to other chemical contaminants (specificity), or physical parameters (pressure, vibrations), and time of integration (data acquisition) should be considered prior to selecting a method. Refer to ASTM D 6399 for aircraft cabin air quality measurement instrumentation recommendations.

5.1 Rubber Cracking Method:

Ozone readily attacks rubber. It causes surface cracking and bleaching. To measure ozone content in air, stretched bands of natural rubber are exposed to ozone contaminated air for a selected time. The average ozone concentration, during the exposure period, is determined by visually comparing the exposed bands with standard samples and by measuring the modulus of elasticity. This method is not exact. Also, it cannot be used to determine ozone concentration variations.

5.2 Potassium/Iodide Method:

Air containing ozone is bubbled through a solution of potassium iodide. The ozone reacts with the potassium iodide forming free iodine and potassium hydroxide. The amount of free iodine formed is proportional to the amount of ozone passing through the solution. The iodine formed is determined by titration with sodium thiosulphate or by changes in the solution color. This is an accurate method for determining average ozone concentration over a long sampling period. It cannot be used to determine rapid ozone concentration changes.

A modification of this method substitutes amperometric titration for color-change titration. This provides a faster response time of 1 to 2 minutes. A system consisting of two electrodes, immersed in the solution, provides continuous measurement of ozone by measuring the electrical reaction of iodine at cathode.

Another modification of this method uses color titration. In this method a volume of the air sample is drawn through a tube containing reactive crystals.

Recently, a color titration method has been proposed on cards. Such color titration data is dependent of exposure duration after protection removal.

The precision, specificity and repeatability of color titration methods are low.

5.3 UV Absorption:

Ozone has a strong absorption maximum at about 2537 angstroms (254 nm), a wavelength produced by mercury vapor lamps. Ozone concentration in an air sample is determined photometrically. The ozone concentration is calculated by the use of Beer Lambert Law:

$$I = I_0 e^{-\alpha LC} \quad \text{(Eq. 1)}$$

or

$$Tr = I/I_0 = e^{-\alpha LC} \quad \text{(Eq. 2)}$$

where:

I = Light Intensity
I_0 = Initial Intensity
e = Neperian base = 2.718
α = Alpha, Absorption coefficient of ozone at 254 nm = 308 ± 4 atm^{-1} cm (in Neperien base)
Alpha is independent of barometric pressure of the sample
L = Optical distance through the sample
C = Ozone concentration in the sample
Tr = Transmittance

The UV absorption system uses one or two chambers: (1) to determine the transmittance of light through an air sample containing ozone (test sample), and (2) to determine the conductance of light through a sample containing zero or a known quantity of ozone (control sample). The chambers are at the same pressure and temperature. Thus, the measured concentration is independent of sample's pressure and temperature.

At a wavelength of 254 nm, this method is highly specific and provides absolute ozone concentration.

$$C:[O_3](ppm) = \frac{10^6}{\alpha L} Ln\left(\frac{I_0}{I}\right) \quad \text{(Eq. 3)}$$

The UV absorption system is recommended for ozone concentration measurement. This method has a measurement accuracy of ±0.2 ppb, can detect concentration as low as 0.5 ppb (1 µg/Nm^3) and can accurately measure from 5 ppb (10 µg/Nm^3) to 10 ppm (20 mg/Nm^3). It has a fast response time of 1 to 2 seconds. All recent devices incorporate microprocessors for automatic correction of pressure and temperature. (Reference ISO 13 964) The specificity, reliability, and repeatability are excellent. UV absorption monitoring systems have been successfully used for several years in aviation and non-aviation applications.

5.4 Electronic Sensors:

Several ozone measurement devices are under development. They are based on conductance change in presence of ozone. Ozone specificity of the sensor is extremely important for true measurement. Several gaseous contaminants (aircraft material generated or passenger generated) are generally present. Sensor specificity must be checked.

6. OZONE CONTROL:

A catalyst (noble metal or metal oxides) or activated charcoal accelerates the decomposition of ozone. The natural decomposition (i.e., ozone natural cracking) is a comparatively slow process.

6.1 Thermal Decomposition:

Ozone in air decomposes at a rate determined by the air temperature.

6.1.1 Physico-Chemistry of Thermal Decomposition: Boberg and Levine, [1962], present an equation for ozone decomposition rate as a function of temperature using the rate constant values measured by Benson and Axworthy, [June 1957].

$$t = 4.62 \times 10^{-11} \times \left[\frac{1}{O_3(\mathrm{final})} - \frac{1}{O_3(\mathrm{initial})}\right] \times e^{27720/T} \quad \text{(Eq. 4)}$$

where:

O_3 = ozone concentration in air, ppm
T = absolute temperature, K
t = time in seconds required for concentration to change from initial to final.
e = Neperian base = 2.718
initial = Initial concentration at time t = 0.0
final = Final concentration at time t = t seconds

According to the above relation, ozone decomposition depends on the absolute temperature and residence time. For example, a reduction from 10 ppmv to 0.1 ppmv takes 27.5 minutes at 260 °C (500 °F) but only 1/3 of a second at 480 °C (900 °F).

6.1.2 Subsonic Airplanes: The outside air temperature rise in the engine compressor depends on the compression pressure ratio, the outside air temperature and the compression process efficiency. The higher the pressure ratio (for constant inlet temperature and compression efficiency) the higher the temperature rise. Outside air is compressed in the engine compressor prior to its delivery to the air conditioning system. Thus, the higher the supply pressure (engine bleed air pressure) to the air-conditioning system the greater the ozone decomposition.

The bleed air temperature on commercial subsonic airplane is typically between 150 and 200 °C (300 to 400 °F). The residence time at this temperature is less than 1/3 of a second. This temperature – time combination does not decompose outside air ozone efficiently. Use of bleed air from a higher engine stage, which is at a higher temperature, increases the ozone decomposition. This method was used for a short duration on the B-747SP to mitigate cabin-air ozone problems when they first appeared as chronic. The air conditioning system was made to operate on higher pressure (high stage bleed) during cruise. However, use of bleed-air at a pressure greater than necessary imposes a severe fuel burn penalty.

6.1.3 Supersonic Airplanes: Supersonic airplanes generally cruise at high altitudes, 18,300 to 21,400 m (60,000 to 70,000 ft). The compression of outside air (at significantly lower pressure than that which exists at lower altitudes of subsonic airplanes) to pressures required by typical air-conditioning systems (air cycle or vapor cycle) causes high temperature. This temperature increase occurs in two consecutive processes:

a. compression through a shock wave (supersonic to subsonic flow), and
b. compression within the engine.

On Concorde, the bleed air temperature during normal cruise is approximately 400 °C (750 °F). This decomposes essentially all ozone within the half second that the air resides at this temperature.

6.1.4 General Aviation Considerations: Thermal decomposition is not a good method for ozone control in the cabin-air of subsonic airplanes. The bleed air temperatures are typically low, 150 to 200 °C (300 to 400 °F), and the residence time is too short to cause any appreciable ozone decomposition. Thus, this method is not practiced on subsonic transports.

Thermal decomposition may be used on high altitude supersonic airplanes for ozone control in the cabin air if the normal engine bleed air temperatures during cruise is high and the residence time adequate to decompose the outside air ozone. Equation 4 may be used to estimate the final ozone concentration entering the air conditioning pack. Supersonic airplanes fly subsonic at lower altitudes during climb and descent. Cabin-air ozone concentrations must be evaluated during these operating conditions to prevent discomfort and show compliance with the regulations.

6.2 Retention Factor:

The Retention Factor, R, is defined as the ratio of cabin-air to outside air ozone concentrations. It is a measure of the amount of outside air ozone that naturally decomposes as it flows through the engine, air-conditioning system equipment and the cabin volume. The dilution effects of cabin air recirculation, used to supplement cabin ventilation, are also included in estimating the retention factor. Retention factor does not include the ozone that decomposes in an ozone converter. R is always less than unity. A low retention factor indicates high decomposition rate of ozone. Retention factor depends on a number of variables: passenger load factor, interior materials, ratio of recirculated to outside air, incoming air ozone concentration, interior surface to volume ratio, air conditioning system design and operational parameters. (Reference Table 4) It cannot be calculated; it must be determined by test at the critical operating (incoming air ozone concentration) condition.

Several investigators have determined R values as typically ranging from 0.75 to 1.00 when there is no cabin air recirculation and from 0.4 to 0.6 when cabin air is recirculated to supplement ventilation and with full passenger load. The R factor for a particular aircraft may differ from these values depending on its design and operational parameters. The FAA accepts a retention factor of 0.7 without requiring a test. (Reference Amendment 25-56 and AC 25-22) It is based on a typical inservice passenger load factor and typical operating conditions, and current design parameters and materials of construction. To qualify for a lower R value submittal of test data is required. The test plan must be submitted to the FAA for approval prior to the conduct of the test.

6.3 Ozone Reduction Methods:

The following methods can be used separately or in combination.

6.3.1 Catalytic Ozone Converter: A catalytic ozone converter decomposes ozone by catalysis (acceleration of a chemical reaction by the addition of a catalyst). The catalyst is neither altered nor consumed in the reaction.

$$\begin{gathered} 2\,O_3 \Rightarrow 2\,O_2 + 2\,O \\ \text{catalyst} \\ 2\,O \Rightarrow O_2 \end{gathered} \qquad \text{(Eq. 5)}$$

The aviation industry has used catalytic converters since 1980. The converter contains a flowthrough honeycomb monolith with a proprietary catalyst coating. See Figure 3 for a typical converter installation. The type of catalyst is governed by the operating temperature and the catalyst quantity and distribution on the required efficiency. New converters can decompose 90% to 98% of the ozone present in the air flowing through it.

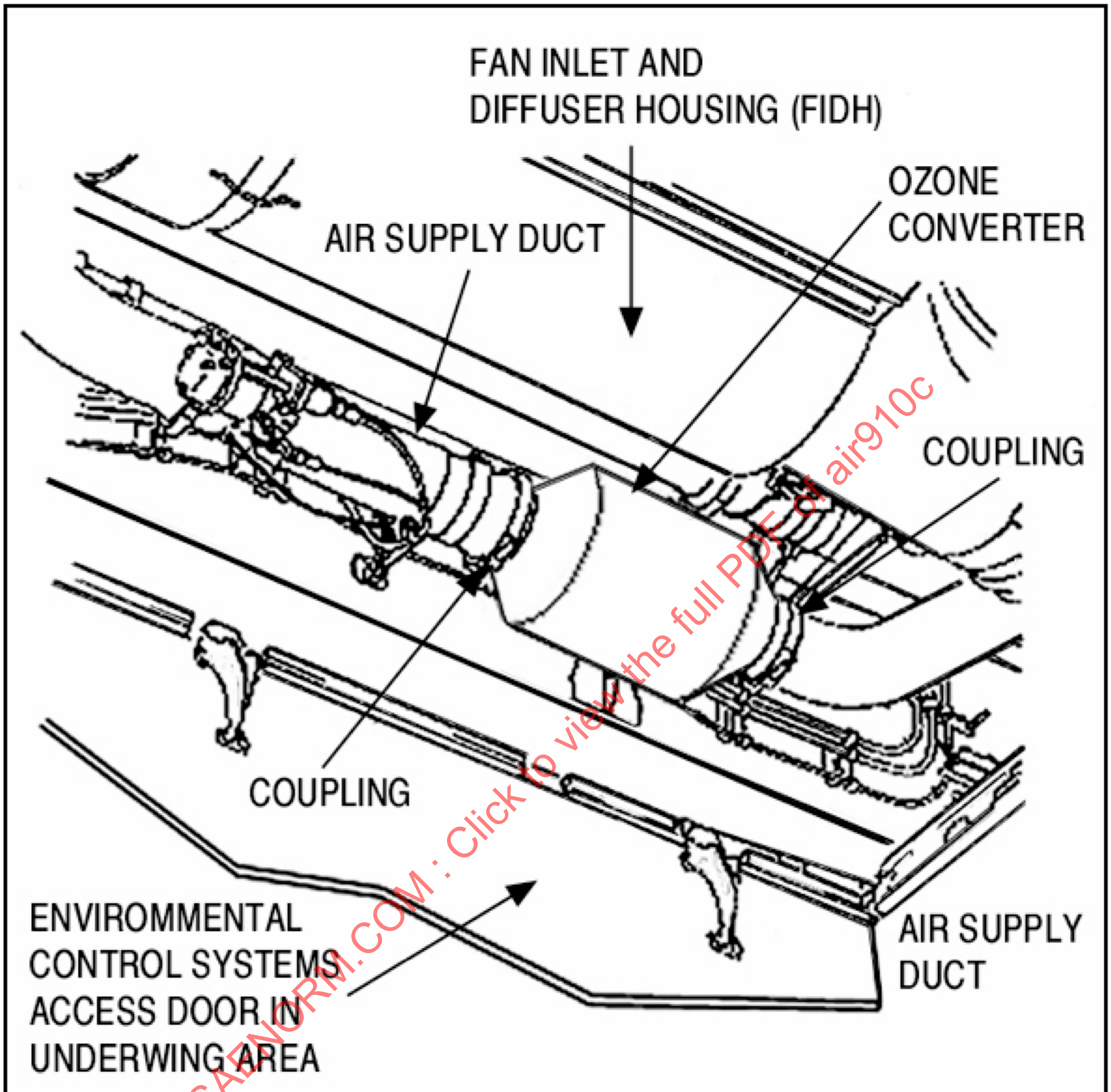

FIGURE 3 - Ozone Converter Installation in Cooling Pack

6.3.1 (Continued):

The catalytic converter is installed upstream of the air conditioning pack. Impurities (hydraulic fluid, unburned fuel/soot, etc.) in the air going to the air conditioning system, over time, mask the catalyst surface. This phenomenon is called catalyst poisoning and reduces converter efficiency as contact between catalyst and the ozone molecules is altered. To minimize converter poisoning several installations bypass the ozone converter when the air conditioning system is using APU or ground air cart air instead of engine air. This prevents premature catalyst poisoning by contaminated airport air.

Converter efficiency cannot be determined by visual inspections or pressure drop measurements. Test (simultaneous supply and discharge air ozone measurement) is the only reliable method for efficiency determination.

The converter, when installed must perform its intended function. That is, it must decompose necessary amounts of ozone to insure cabin-air ozone concentrations are within allowable limits. AC 120-38 provides information on the acceptable method for calculating the minimum acceptable converter efficiency necessary for compliance. Converter overhaul (refurbishment) time is determined using this method and the expected in-service decrease in converter efficiency. The overhaul time is identified in the Maintenance Manual.

Ozone converters were first introduced in 1980 as optional equipment to help operators comply with the requirements of 14 CFR § 121.578. Several operators installed ozone converters based on the needs of their route structure (altitude, latitude and flight time). Non-U.S. operators do not have to comply with the requirements of 14 CFR § 121.578. New aircraft models such as A-340 and B-777 that are certified to the requirements of 14 CFR § 25.832 Amendment 25-50 or subsequent, (effective date January 1, 1980), incorporate ozone converters as basic equipment. Retrofit installation of ozone converters is not required on airplanes that do not include 14 CFR § 25.832 Amendment 25-50 in their certification basis. However, these aircraft are required to comply with the requirements of 14 CFR § 121.578 if they engage in interstate or overseas air transportation under a certificate of public conveyance issued by the U.S. government. These are the reasons for the presence or absence of an ozone converter on an airplane model.

6.3.2 Activated Carbon Filter: Activated carbon is a specially processed charcoal. It has a high capacity for removing ozone from air. The adsorption effectiveness of charcoal is high at low temperatures. It is usually installed at the outlet of the air-conditioning system. It loses efficiency rapidly, although it can be recycled. Also, it is heavy and bulky, and has large pressure drop compared to a catalytic converter of equivalent ozone removal capability. Activated carbon filtration was used on the B-747 aircraft, on an interim basis, before the introduction of the catalytic converter.

6.3.3 Zeolites: Zeolites belong to a class of hydrated silicates of aluminum and either sodium or calcium. When suitably activated, molecular sieve type zeolites show excellent ozone decomposition characteristics at low temperatures, 24 °C (75 °F). Due to weight, volume, pressure drop and service life constraints, zeolites have not been used in transport category airplanes.

6.3.4 Photochemical: Ozone forms by the photochemical action of ultraviolet light of less than 2450 angstroms. Light of longer wavelength, greater than 2450 angstrom and less than 11,500 angstroms, decomposes it. Visible red light also decomposes it. Visible light spectrum ranges from about 4000 to 7700 angstroms. This technique is not yet used in aviation. However, it is used in industrial applications.

6.4 Altitude/Latitude Limitations:

Compliance with the requirements of 14 CFR § 25.832 and 14 CFR § 121.578 may be shown by analysis, as described in Appendix. The analysis must show that based on operational procedures and or limitations the cabin air ozone concentrations will not exceed the allowable limits. The operational limitations (altitude, latitude, time of the year, etc) are determined using the 84% confidence level ozone concentrations for 14 CFR § 121.578 and for 14 CFR § 25.832. (Reference AC 120-38 and AC 25-22) The analysis method is also described in FAA-EQ-78-03. The operational limitations are required to be documented in the FAA approved Airplane Flight Manual.

Compliance with allowable ozone levels by operational procedures can impose significant fuel burn penalty. The penalty may exceed the cost of catalytic converters.

7. COMPLIANCE WITH AVIATION REGULATIONS:

Compliance with 14 CFR § 25.832 requires demonstration (by test or analysis) that the cabin ozone concentration will not exceed the stated limits at the maximum atmospheric ozone concentration expected in service within the certified operating envelope (altitude, latitude, season). It should be noted that while 14 CFR § 121.578 explicitly allows the use of atmospheric ozone concentration levels with a statistical confidence of 84% for demonstration of compliance, allowance to use 84% confidence level statistical ozone concentration data in lieu of 100% confidence level data in showing compliance with 14 CFR § 25.832 is provided by interpretation of the rule in FAA Advisory Circular AC 25-22. The regulation does not specify a design solution. It allows the applicant to use the most effective means (retention factor, ozone converter, altitude and latitude limitations, seasonal restrictions, and all possible combinations of these) to demonstrate compliance. FAA has accepted operational limitations, documented in the FAA approved Airplane Flight Manual as a means of compliance. These limitations restrict the airplane to certain maximum altitudes based on the latitude and time of year. This method is also acceptable in demonstrating compliance to 14 CFR § 121.578. However, it must be noted that 14 CFR Part 25 approval is not geographically limited. Therefore, charts need to be available for ozone limitations globally for this method of complying with 14 CFR § 25.832.

Equipment (filter or converter) efficiency and airplane retention factor must be determined at representative ozone concentrations when such items are used to demonstrate compliance. The FAA approved outside ambient ozone concentration data (maximum and 84% confidence level) is listed in FAA-EQ-78-03 and AC 120-38. Seasonal levels in the Southern Hemisphere are believed to be similar to the levels in the Northern Hemisphere. The FAA allows the use of interpolation technique to determine ozone concentrations at intermediate altitudes and latitudes. Figure 1 provides data at high (80°N) latitude from FAA-AEQ-77-13.

Acceptable analysis technique is documented in AC 120-38.

7.1 Cabin-Air Ozone Sampling:

Ozone is an oxidant. It is also unstable. It reacts with other materials (oxidizes them) and self-decomposes (converts to oxygen). Thus, sampling location is important. Industry practice is to sample air at seated head-level in the passenger compartment and flight deck, and standing headlevel in the galley. Ozone concentration varies from fore to aft and also from the floor to ceiling in the compartment. Representative cabin-air ozone measurement requires that (1) tubing and equipment not react with ozone, and (2) samples from several locations within the cabin be collected and analyzed. Teflon tubing is inert when exposed to ozone. The FAA should be requested to approve the number of samples and their locations.

7.1.1 Sampling Conditions: Ozone concentration depends on a number of factors per Table 4. Data should be taken at a statistically significant number of locations and during all critical operating modes (varying the number of recirculation fans and or air conditioning packs operated) to show compliance with the applicable regulation.

7.1.2 Tests:

7.1.2.1 Retention Factor: Ozone concentration, in nature, varies continuously. This makes it difficult to test an airplane at "critical" outside ozone levels that may be encountered in service. In addition, cabin-air ozone concentration lags outside air concentration due to the cabin volume and interiors. FAA accepts ground test to show compliance with the regulations. (Refer to Advisory Circular AC 25-22) The test is conducted by injecting ozone at the maximum levels the airplane would encounter in service into the air-conditioning supply air upstream of the pack flow control and shut off valve. Alternatively, ground tests may be conducted utilizing ambient ozone in regions with high natural levels of ozone providing the FAA finds this method acceptable. The critical test condition is determined from the airplane certification objective: ceiling altitude, intended region of operation (latitudes), supply air temperatures (engine characteristics, and pneumatic system design), typical payload. The supply-air temperature to the pack should be representative of the in-service supply air temperature, at the critical operating altitude. Pressure is not important. Ozone decomposition by air-conditioning equipment material and in system's thermodynamic processes depends on absolute concentration and temperature (thermal and compression). Note that Amendment 25-56 states the FAA accepts a default 0.7 retention factor without a test. See also 6.2.

7.1.2.2 Ozone Filter or Converter Efficiency: The efficiency of ozone filter or ozone converter depends on absolute ozone concentration, the rate, and the gas temperature. This test is best performed in the laboratory. Ozone is injected in the air stream upstream of the filter or converter. The ozone concentrations are measured upstream and downstream of the filter or converter. The test must be conducted at several inlet air ozone concentrations. The following relation is used to determine the efficiency:

$$\text{Efficiency} = [\text{Inlet concentration} - \text{Discharge concentration}] / \text{Inlet concentration} \qquad \text{(Eq. 6)}$$

The efficiency of a filter or converter changes with operating time. To ensure regulations are complied with throughout the life of the airplane the minimum in-service efficiency of the filter or converter must be established. This is accomplished by determining the efficiency of in-service units. A maintenance or overhaul time is established such that a degraded filter or converter can still comply with the regulations.

7.1.3 Compliance Report: The compliance report must consist of data (analysis and test) necessary to show compliance with the regulations. It should provide information on the measurement equipment (operating principle, reliability, repeatability, and accuracy). The measurement equipment must be calibrated before and after the test. The report should also provide assumptions, relevant information on equipment (packs, fans, filters, converters) and operating conditions (outside ozone concentration, passenger load factor, air-conditioning system supply temperature and pressure, flow rates, etc). The limitations, if any, must be identified.

8. NOTES:

8.1 Revision Indicator:

The change bar (|) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document.

8.2 Key Words:

Ozone, ozone converter, high altitude flight, concentration limits, exposure limits, ozone measurement, retention factor, sea-level equivalent

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