



AEROSPACE INFORMATION REPORT

AIR7521™

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

RATIONALE

This document provides supplementary information for ARP4418. These data and reference values are for information only, and are not intended for developing exposure limits for aircraft bleed air quality.

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Documents

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1. SCOPE

This document summarizes published measurement data and reference values for marker chemical compounds listed in ARP4418 (see 2.1.1) potentially found in aircraft engine bleed air.

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 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.

ARP4418 Procedure for Sampling and Measurement of Engine and APU Generated Contaminants in Bleed Air Supplies from Aircraft Engines

2.1.2 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.

2.1.2.1 Jones, B.; Amiri, S.N.; Roth, J.; and Hosni, M.H. (2017). The nature of particulates in aircraft bleed air resulting from oil contamination, LV-17-C046. *Presented at IAQ in the Airline Industry, Conference Paper Session 12, ASHRAE Winter Meeting, Las Vegas, NV.*

2.1.2.2 Nagda, N.L.; Rector, H.E.; Zhidong, L.; and Hunt, E.H. (2000). Determine aircraft supply air contaminants in the engine bleed air supply system on commercial aircraft. *Final Report for ASHRAE Research Project RP-959.*

2.1.2.3 Space, D.R.; Salgar, A.K.; Scheer, D.A.; Jones, B.W.; and Amiri, S.N. (2017). Experimental determination of the characteristics of lubricating oil contamination in bleed air, LV-17-C047. *Presented at IAQ in the Airline Industry, Conference Paper Session 12, ASHRAE Winter Meeting, Las Vegas, NV.*

2.1.3 USEPA Publications

2.1.3.1 U.S. Environmental Protection Agency (EPA). National Ambient Air Quality Standards, Code of Federal Regulations, Title 40 Part 50 (40 CFR 50). <https://www.epa.gov/criteria-air-pollutants>.

2.1.3.2 US Environmental Protection Agency (EPA). (2006). Summarized data of the building assessment survey and evaluation (BASE) study, *Washington, DC: EPA 402-C-06-002*. <https://www.epa.gov/indoor-air-quality-iaq/summarized-data-building-assessment-survey-and-evaluation-study>.

2.1.4 Other Publications

2.1.4.1 Armbruster, D.A., and Pry, T. (2008). Limit of blank, limit of detection and limit of quantitation. *Clinical Biochem Rev. Aug. 29(Suppl1)*, S49-S52.

2.1.4.2 American Conference of Governmental Industrial Hygienists. (2017). Threshold limit values for chemical substances and physical agents and biological exposure indices. *1330 Kemper Meadow Drive, Cincinnati, OH 45240-1634*. www.acgih.org.

2.1.4.3 United States Centers for Disease Control. (2016). Pocket guide to chemical hazards. *CDC NIOSH*. <https://www.cdc.gov/niosh/docs/2005-149/pdfs/2005-149.pdf>.

- 2.1.4.4 Federal Institute for Occupational Safety and Health, Federal Republic of Germany. (2017). Technical rules for hazardous substances, TRGS 900 Arbeitsplatzgrenzwerte (Workplace limits). <https://www.baua.de/ags>.
- 2.1.4.5 Crump, D.; Harrison, P.; and Walton, C. (2011). Aircraft cabin air sampling study: Parts 1 and 2 of the final report. *Institute of Environment and Health, Cranfield University, Cranfield, England*.
- 2.1.4.6 Devos, M. Ed.; Patte, F.; Rouault, J.; van Gemert, L.J. (1990). Standardized human olfactory thresholds. *IRL Press at Oxford University Press*.
- 2.1.4.7 EASA. (2007). CS-25 Amendment 4 - certification specifications for large aeroplanes, CS-25. *European Aviation Safety Agency*. https://www.easa.europa.eu/system/files/dfu/CS-25_Amdt4.pdf.
- 2.1.4.8 FAA. (1996). Code of Federal Regulations, Title 14 aeronautics and space, U.S. Federal Aviation Administration, Department of Transportation, Part 25 airworthiness standards, Section 831 ventilation: transport category airplanes.
- 2.1.4.9 Fox, R.B. (2012). Assessing aircraft supply air to recommend compounds for timely warning. *Northcentral University*. <https://pqdtopen.proquest.com/doc/1021859974.html?FMT=ABS>.
- 2.1.4.10 Health Canada. (2006). Residential indoor air quality guideline: Formaldehyde. *Health Canada, Ottawa*. <https://www.canada.ca/en/health-canada/services/publications/healthy-living/residential-indoor-air-quality-guideline-formaldehyde.html>.
- 2.1.4.11 Health Canada. (2010). Residential indoor air quality guideline: Carbon monoxide. *Health Canada, Ottawa*. <https://www.canada.ca/en/health-canada/services/publications/healthy-living/residential-indoor-air-quality-guideline-carbon-monoxide.html>.
- 2.1.4.12 Health Canada. (2011). Residential indoor air quality guideline: Toluene. *Health Canada, Ottawa*. <https://www.canada.ca/en/health-canada/services/publications/healthy-living/residential-indoor-air-quality-guideline-toluene.html>.
- 2.1.4.13 Health Canada. (1995). Exposure guidelines for residential indoor air quality, a report of the federal-provincial advisory committee on environmental health and occupational health. *Health Canada, Ottawa*. <http://publications.gc.ca/collections/Collection/H46-2-90-156E.pdf>.
- 2.1.4.14 International Standard ISO8573-1. (2010). Compressed air part 1: Contaminants and purity classes. *International Standard Organization, Switzerland*.
- 2.1.4.15 Logue, J.M.; McKone, T.E.; Sherman, M.H.; and Singer, B.C. (2011). Hazard assessment of chemical air contaminants measured in residences. *LBNL Report No. 3650-E, Lawrence Berkeley National Laboratories, Environmental Energy, Technologies Division*.
- 2.1.4.16 Mann, G.W.; Eckels, S.J.; and Jones, B.W. (2014). Analysis of particulate size distribution and concentrations from simulated jet engine bleed air incidents. *HVAC&R Research* 20, 780–789, DOI: 10.1080/10789669.2014.950922.
- 2.1.4.17 California Office of Environmental Health Hazard Assessment (OEHHA). (2017). Toxic air contaminants. <http://oehha.ca.gov>.
- 2.1.4.18 Regulamentos Brasileiros de Homologação Aeronáutica, part 25. Aeronautical Products Certification Branch (GGCP). *CTA-IFI Building, Praça Marechal Eduardo Gomes, No. 50, Vila das Acácias, 12231-970 São José dos Campos, SP, Brazil*.
- 2.1.4.19 Rosenberger, W.; Beckman, B.; and Wrbitzky, R. (2015). Airborne aldehydes in cabin-air of commercial aircraft: measurement by HPLC with UV absorbance detection of 2,4-dinitrophenylhydrazones. *Journal of Chromatography B*. 1019: 117-127.
- 2.1.4.20 Ruth, J.H. (1986). Odor thresholds and irritation levels of several chemical substances: a review. *American Industrial Hygiene Association Journal* (47): A142-A151.

- 2.1.4.21 Spengler, J.D.; Vallarion, J.; McNeely, E.; Estephan, H.; and Sumner, A.L. (2012). In-flight/onboard monitoring: ACER's component for ASHRAE 1262, Part 2, Report No. RITE-ACER-CoE-2012-6. *National Air Transportation Center of Excellence for Research in the Intermodal Transport Environment (RITE) Airliner Cabin Environmental Research (ACER) Program*.
- 2.1.4.22 Schuchardt, S.; Bitsch, A.; Kochj, W.; and Rosenberger, W. (2017). Final report: preliminary cabin air quality measurement campaign (CAQ) EASA.2014.C15, and preliminary cabin quality measurement campaign (CAQ II) EASA.2014.C15.SU01. *European Aviation Safety Agency (EASA)*. https://www.easa.europa.eu/system/files/dfu/EASA%20CAQ%20Study%20Final%20Report_21.03.2017.pdf.
- 2.1.4.23 Transport Canada 525.831. Part V – airworthiness Chapter 525 - transport category aeroplanes. Ventilation and heating. <http://www.tc.gc.ca/eng/civilaviation/regserv/cars/part5-standards-525-sub-d-1741.htm#525.831>.
- 2.1.4.24 U.S. Department of Labor, Occupational Safety and Health Administration. Code of Federal Regulations, Title 29, Part 1910.1000-1910.1450. www.osha.gov.
- 2.1.4.25 Wise, P.M.; Wysocki, C.J.; and Tomas, R. (2003). Time-intensity ratings of nasal irritation from carbon dioxide. *Chem. Senses* 28:751-760.
- 2.1.4.26 World Health Organization. (2000). Air quality guidelines for Europe, 2nd edition. *World Health Organization Regional Publications, European Series No. 91*. World Health Organization, Regional Office for Europe, Copenhagen, www.euro.who.int/document/e71922.pdf.

2.2 Definitions

BASE: Building Assessment Survey and Evaluation Study by the US Environmental Protection Agency.

EXPOSURE LIMIT: An environmental exposure level not to be exceeded over a specified duration of time. Users are cautioned that published exposure limits developed for a specific environment are not necessarily applicable to other environments and that limits are developed for individual chemicals, not chemical mixtures.

LIMIT OF BLANK (LOB): LOB is the highest apparent analyte concentration expected to be found when replicates of a blank sample containing no analyte are tested. $LOB = \text{mean}_{\text{blank}} + 1.645 \times (SD_{\text{blank}})$ (see 2.1.4.1).

LIMIT OF DETECTION (LOD): LOD is the lowest analyte concentration likely to be reliably distinguished from the LOB and at which detection is feasible. LOD is determined by utilizing both the measured LOB and test replicates of a sample known to contain a low concentration of analyte. $LOD = LOB + 1.645 \times (SD_{\text{low concentration sample}})$ (see 2.1.4.1). LOD should exclude all sources of spurious readings. Laboratories may use other definitions for LOD.

LIMIT OF QUANTIFICATION (LOQ): LOQ is the analyte concentration sufficient to produce analytical signals that meet predetermined targets for bias, imprecision, and total error. $LOQ \geq LOD$ (see 2.1.4.1).

SUMMATION PRINCIPLE: A principle with an associated formula to apply to exposure guidelines for similar chemical compounds with similar action on target organs, such that the combined exposure is evaluated mathematically.

2.3 Acronyms

A320: Airbus Model A320

A380: Airbus Model A380

ACGIH: American Conference of Governmental Industrial Hygienists

ANAC: National Civil Aviation Agency (Brazil)

ASHRAE: American Society of Heating, Refrigeration, and Air-Conditioning Engineers

CAS: Chemical Abstract Service

CDC: Centers for Disease Control

EASA: European Aviation Safety Agency

EPA: Environmental Protection Agency (USA)

FAA: Federal Aviation Administration

LBNL: Lawrence Berkeley National Laboratories

LOB: Limit of Blank (see 2.2)

LOD: Limit of Detection (see 2.2)

LOQ: Limit of Quantification (see 2.2)

MAK: Maximum Concentration and Biological Tolerance Values at the Workplace (Germany)

n: Sample population size

NAAQS: National Ambient Air Quality Standards (USEPA)

NIOSH: U.S. National Institute for Occupational Safety and Health

OEHHA: California Office of Environmental Health Hazard Assessment

OSHA: U.S. Occupational Safety and Health Administration

RBHA: Regulamentos Brasileiros de Homologação Aeronáutica

REL: Recommended Exposure Limit

USDOL: United States Department of Labor

VOC: Volatile Organic Compounds

WHO: World Health Organization

2.4 Units

2.4.1 Physical Quantities

atm = 1 atmosphere pressure = 101.325 kPa

CFM = Cubic feet per minute

°C = degrees Celsius

°F = degrees Fahrenheit

g = gram

Hz = Hertz (1 per second)

K = Kelvin

m = meter

Pa = pascal

ppmV = parts per million by volume

ppbV = parts per billion by volume

s = second

slpm = standard liters per minute

2.4.2 Prefixes

k = kilo, 10^3

c = centi, 10^{-2}

m = milli, 10^{-3}

μ = micro, 10^{-6}

n = nano, 10^{-9}

3. PURPOSE

The purpose of AIR7521 is to provide additional reference information not provided in ARP4418 for marker compounds listed in Table 1 of that document. These relate to potential engine-generated contaminants in the bleed air during steady-state engine conditions (see 2.1.1.1). These data and reference values are for information only and are not intended for developing exposure limits for aircraft bleed air quality. This document does not provide any recommendations regarding whether the user could or should modify exposure limits for application to potentially complex mixtures of contaminants (e.g., thermal decomposition products of oil, engine exhaust, etc.) in aircraft engine bleed air that is intended for ventilation supply air.

4. REFERENCE DATA

A range of sampling and analytical methods are represented within the data tables of this AIR. Individual references can be reviewed for sampling and analysis details. Acetaldehyde and formaldehyde samples are typically collected by drawing a bleed air sample through a bed of silica that has been coated with dinitrophenol hydrazine to stabilize the aldehydes. Most procedures now require ozone to be removed before the air comes in contact with the media that will hold the sample. Acrolein and toluene may be analyzed along with other VOC samples. VOC samples are collected in evacuated canisters, using a range of adsorbent media, or using online analyzers.

The samples represented in the results tables have been collected over study periods of up to 20 years, and in a range of environments including aircraft bleed air, aircraft cabins, homes, and offices. The diversity of these samples over time provides the opportunity to capture a broad range of data from a variety of environments while using a range of laboratory and field analytical equipment and methods. Analytical methodology for aircraft and building samples is virtually the same, although sample collection may have been adapted to the specific sample being targeted in the building or aircraft environment. The data here may not be representative of all environments.

Table 1 lists several published exposure values for the marker compounds.¹

Table 2 lists several published sensory threshold values for the marker compounds.¹

¹ These data have not shown correlation with cabin air exposure and may not be used to set bleed air limits.

Table 3 lists a compilation of reported values from several studies containing aircraft engine bleed air measurements.^{2, 3}

Table 4 lists a compilation of reported values from several cabin air sampling studies.³

Table 5 lists a compilation of mean values from building and residence surveys.⁴

Table 6 lists the 65th and 75th percentiles for engine bleed sampling data for acetaldehyde, formaldehyde, toluene, and carbon monoxide.

The current AIR does not address ultrafine particle data because ARP4418 does not include ultrafine particle test and measurement methodology. Recent studies have begun to define the relationship between ultrafine particle size fraction/count and oil contamination in bleed air (Crump et al., 2011, [see 2.1.4.5], Jones et al., 2017, [see 2.1.2.1], Space et al., (2017) [see 2.1.2.3]; and Mann et al., (2014) (see 2.1.4.16)). Ultrafine particle data sets will be included in a future revision of this AIR.

Figures 1 through 5 show the 25th through 85th percentile range of the data that are listed in Tables 3 and 4 for acetaldehyde, formaldehyde, acrolein, toluene, and carbon monoxide. The concentration of each of those marker compounds does not change significantly between the 25th to 65th percentile, but does start to rise at higher percentiles. As such, data above the 65th percentile range (see Table 6) could be indicative of an underlying source of external or internal contamination in bleed air measurement. The user would need to determine if the contaminant source is external or internal to the engine, or if there is a measurement issue. Uncorrected carbon dioxide measurements from literature are available in Table 3.

Figures 1 through 4 illustrate the range of the Limits of Detection (LOD) values and Limit of Quantification (LOQ) values for some laboratories that perform environmental analyses. Variation in LOD and LOQ values may be due to differences in laboratory analytical methods, instrumentation variation, and the range of sample volumes analyzed. Figure 5 illustrates measured values for CO against LOD and LOQ values reported in ARP4418. These charts illustrate that in most measurement samples the amount of analyte will likely fall in the concentration range between the LOD and LOQ.

² In this table, 2.1.4.9 reports bleed air quality data collected on 94 engines and APUs mounted on engine tests stands by a major APU/engine manufacturer from 1997 to 2011, consisting of 77 to 254 samples, depending on the marker compound. This measurement data include APUs and engines returned because of bleed air quality concerns, and engines or APUs under engineering development and certification. Reference 2.1.2.2 reports cabin air quality data collected during 10 flights (including bleed air during six of those flights) in 1999, with a range of 6 to 48 samples, depending on the marker compound. There were no reported fume events on these 10 flights. Space et al. (2017) (see 2.1.2.3) consists of data from a simulated forward-bearing failure of three runs on a single engine with injection of 1200 g/h engine oil upstream of the engine compressors.

³ Data in this table are uncorrected; specifically, aircraft engine inlet measurements were not subtracted from aircraft cabin air measurements. Some data were collected in-flight.

⁴ These air quality data collected in homes and offices have not been correlated with conditions in an aircraft cabin. One of the ways that the aircraft cabin differ inflight from sea level is the lower air pressure and corresponding reduction in oxygen levels.