Meeting

Aircraft cabin air: Basis of the regulatory values for carbon dioxide

This is a paper for discussion.

This does not represent the views of the Committee and should not be cited.

Introduction

1. This paper is part of the series on aircraft cabin air and follows the paper presented to the Committee in December (TOX/2022/65) which outlined the concentrations of CO and CO2 in aircraft cabin air, and compared these to aircraft regulatory values and occupational standards. This paper and the minutes of the discussion are attached at Annex A.

2. This paper explores the basis of regulatory and occupational standards for CO2 so conclusions can be made regarding the potential risks of CO2 in cabin air.

Background

3. In 2007, the Committee on Toxicity (COT) published a statement on aircraft cabin air, relating to organophosphate (OP) compounds, the cabin air environment, ill-health in aircraft crews and the possible relationship to smoke/fume events in aircraft (COT, 2007). Subsequently, the COT reviewed the results of Department for Transport (DfT) - funded aircraft cabin environment research commissioned in response to recommendations made by COT in 2007, after which the COT issued a position statement on cabin air (COT, 2013).

4. The COT has now been asked by DfT to investigate if any new data have been published and to re-evaluate their previous view in the original statement from 2007 (COT, 2007) and position statement from 2013 (COT, 2013). The COT reviewed an introductory paper on this topic on cabin air in May 2022 (TOX/2022/30), which provided a full background to the Committee’s previous

conclusions. Following the May 2022 COT meeting, the request of COT was further refined to: “Is there evidence of exposure to chemical contaminants in cabin air that could have long-term health impacts, either from acute exposures or due to long-term low level exposures including mixtures, e.g., of volatile organic compounds (VOCs)?”.

5. The levels of VOCs in aircraft compared with other modes of transport (TOX/2022/46) and work environments (TOX/2022/55) were presented in the September 2022 and October 2022 meetings, respectively.

6. Following the September 2022 COT meeting, it was agreed that consideration should also be made of whether there is evidence that exposure to carbon monoxide (CO) or carbon dioxide (CO2) in cabin air could have long-term health impacts. This was discussed in December 2022 (TOX/2022/65). At that time the Committee requested further information on the basis of the regulatory standards and guidelines for CO2 to enable conclusions to be drawn as to whether there might be any potential risks from exposure to CO2 in the aircraft cabin.

Overview of standards and guidelines for CO2

7. Various standards, guidelines and regulations exist related to air quality in aircraft, including levels for CO2. Table 1 shows specific upper limits for CO2 from Europe, US, and China (Chen et al., 2021) and workplace exposure limits (WELs) in UK.

Table1. Aircraft regulatory values for CO2 in Europe, US, and China (cited in Chen et al., 2021).

FAR (US) (ppm)	**ASHRAE (US withdrawn*) (ppm)**	**JAR (EU) (ppm)**	**EASA CS (EU) (ppm)**	**BS-EN4618 (EU; withdrawn**) (ppm)**	**CCAR (China) (ppm)**	**EH40/2005 Workplace exposure limits (ppm)**
5000	1000	30000	5000	20000; 15 min 5000; peak 2000	5000	5000; 8-hour PEL

* withdrawn.

**withdrawn as a result of a decision of the European committee CEN/BT 31/2013.

FAR=Federal Aviation Regulations; ASHRAE=American Society of Heating, Refrigerating and Air-Conditioning Engineers; JAR=Joint Airworthiness Requirements; CCAR=Chinese Civil. Aviation Regulations; EASA = European Aviation Safety Authority; CS = Certification. Specifications; PEL = Permissible Exposure Limit (Workplace exposure limit.)

Aircraft air quality standards

8. Since passage of the US Federal Aviation Act in 1958, the Federal Aviation Agency (FAA) maintains authority over the regulations related to operation and safety of civil aircraft (Public Law 85–726). The FAA exercised its option to regulate the safety and health of airline cabin workers beginning in 1975 (40 FR 29114, DOT 1975). Federal Aviation Regulations (FARs) that have been subsequently promulgated by the FAA to govern air quality in commercial aircraft includes CO2 (14 CFR 21).

9. Similarly, the European Joint Airworthiness Authority (JAA) regulates European cabin air through Joint Aviation Regulations (JAR) (Cone, 2005 cited in Hocking and Hocking, 2005).

10. The airworthiness ventilation regulation for transport aircraft, FAR/JAR 25.831 a/b was established in 1965 and is the major ventilation regulation that must be met for an aircraft to be considered fit for flight (Best and Michaelis, 2005 cited in Hocking and Hocking, 2005).

11. When the regulation came into effect, part b was thought to only cover carbon monoxide, carbon dioxide or ozone and all other contaminants were not considered. Authors noted that ‘Some regulators claim that aircraft toxicants are more of an occupational health and safety (OHS) issue than an air safety issue. For example, the UK Civil Aviation Authority (CAA) has recently advised[1] [7] that crew discomfort such as headaches, nausea and irritation due to contamination is not its responsibility unless the safety of flight and landing are affected. This is not in the intent of airworthiness regulation 25.831a, which implies that undue discomfort and fatigue has the ability to affect crew performance and therefore could impair flight safety’.

12. Occupational exposure standards may be inadequate to protect non-workers, for example passengers. Oil leaks from engines at high pressure and

temperature may pyrolise before it enters the cabin, producing CO_2 and CO. Carbon dioxide is produced in the presence of an abundance of oxygen, whereas CO is produced where stoichiometric concentrations of oxygen are lacking (usually in conditions of incomplete combustion) (Winder and Michaelis, 2005 cited in Hocking and Hocking, 2014).

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)

13. Indoor concentrations greater than 1000 ppm have been associated with increases in self-reported, nonspecific symptoms (sick building syndrome (SBS)), as well as decreased performance of office workers and school workers. Other contaminants or environmental parameters were not controlled for. Therefore, elevated CO_2 concentrations likely served as indicators of inadequate ventilation that increases the concentration of all contaminants with indoor sources (Persily 2015; Lowther et al. 2021 as cited in ASHRAE, 20220.

14. Carbon dioxide is considered nontoxic at concentrations up to 5000 ppm, which is the U.S. federal standard (Permissible Exposure Level) for workplaces set by the Occupational Safety and Health Administration (OSHA, 2017 cited in ASHRAE, 2022).

15. Many countries have proposed mandatory or suggested guideline values for indoor CO_2 in non-industrial spaces. The ASHRAE Position Document on Indoor Carbon Dioxide (2022) notes that ‘the rationales supporting these guideline values are not necessarily provided in the reference documents’.

16. Indoor CO_2 limits are in the range of 1000 ppm but can be as high as about 1500 ppm. They are generally intended for the management of generic indoor air quality (IAQ) concerns and SBS symptoms (ASHRAE, 2022).

17. Research on body odour perception, that showed CO_2 was not considered a pollutant but rather a marker of body odour perception, since humans emit both CO_2 and bioeffluents at rates related to their metabolism ((Lemberg (date not given); Yaglou (date not given); Persily 2015 as cited in ASHRAE, 2022), was used to develop the ventilation requirements in ASHRAE and European Committee for Standardization (CEN) standards. The 1989 edition of ASHRAE's ventilation standard, Standard 62 (subsequently Standard 62.1), had a CO_2 limit of 1000 ppm, but this was removed from subsequent editions due to its common misinterpretation.

18. Therefore, despite many references to the contrary, ANSI/ASHRAE Standard 62.1 (ASHRAE, 2019) does not provide a limit value for indoor CO_2. However, misunderstanding of information in previous editions of the standard still lead to the 1000 ppm limit being incorrectly attributed to ASHRAE (ASHRAE, 2022).

Federal Aviation Regulations (FAR)

19. In the United States, the airline industry is regulated by the FAA which has established FARs to govern the operational requirements for commercial aircraft. Currently the FARs address only a few cabin environmental parameters that might affect safety aspects of crew performance, and to a lesser extent, might protect passengers from adverse health effects and discomfort. Such parameters include carbon dioxide and carbon monoxide. The National Research Council report (NRC 2002 as cited in Spengler, 2012) noted that FARs may be inadequate to protect the health of some members of the flying public.

20. The FARs for ventilation states ‘Crew and passenger compartment air must be free from harmful or hazardous concentrations of gases or vapors. In meeting this requirement, the following apply: Carbon dioxide concentration during flight must be shown not to exceed 0.5 percent by volume (sea level equivalent) in compartments normally occupied by passengers or crewmembers.’ (FAR, 2019).

21. No further information is available.

European Aviation Safety Authority (EASA)

22. In EU, the airline industry is regulated by the EASA by implementing regulations on Air Worthiness.

23. The Certification Specifications (CS) for ventilation (CS 25.831), states ‘Carbon dioxide concentration during flight must be shown not to exceed 0·5 % by volume (sea level equivalent) in compartments normally occupied by passengers or crewmembers’ (EASA, 2019).

24. The Acceptable Means of Compliance (AMC) for ventilation (AMC 25.831(a)) states ‘For probable failure conditions, the ventilation system should be designed to provide enough fresh air to prevent the accumulation of odours and pollutants such as carbon dioxide. Under these conditions, the supply of fresh air should not be less than 0.18 kg/min (0·4 lb/min) per person for any period

exceeding five minutes. However, temporary reductions below this flow rate may be accepted, provided that the compartment environment can be maintained at a level which is not hazardous to the occupant; for this purpose, the applicant may refer to international cabin air quality standards'.

25. No further information is available.

BS-EN4618

26. BS-EN4618 on Aerospace series – Aircraft internal air quality standards, criteria and determination methods was withdrawn as a result of a decision of the European committee CEN/BT 31/2013. No replacement was provided (BS-EN4618).

Chinese Civil Aviation Regulations (CCAR)

27. The CCAR describe air worthiness standards for use by the airline industry in China (CCAR, 2016). CCAR section 25.831 on ventilation states 'Carbon dioxide concentration during flight must be shown not to exceed 0.5 percent by volume (sea level equivalent) in compartments normally occupied by passengers or crewmembers'.

28. No further information is available.

Occupational standards

Health and Safety Executive (HSE)

29. The HSE publication EH40/2005 Workplace Exposure Limits presents workplace exposure limits (WELs) for CO2 (HSE, 2020).

30. The long-term exposure limit (8-hr time weight average (TWA)) is 5000 ppm and the short-term exposure limit (15-min) is 15000 ppm.

31. No information regarding the derivation of such WELs is available. Previous EU limits were updated in the second list of Indicative Occupational Exposure Limit Values (IOELV) in implementation of Council Directive 98/24/EC and amending Directives 91/322/EEC and 2000/39/EC in 2006 (HSE, personal communication).

Occupational Safety and Health Administration (OSHA) and National Institute for Occupational Safety and Health (NIOSH)

32. The Occupational Safety and Health Act was adopted in 1970 to regulate health and safety provisions for workers (Public Law 91–516). Exemptions from OSHA coverage included workers in industries regulated by other agencies such as the Airlines (FAA) (Cone, 2005 cited in Hocking and Hocking, 2005).

33. For other workplaces, OSHA and NIOSH have established a TWA limit value for CO2 of 5000 ppm for airborne exposure in any 8-hour work shift during a 40-hour work week and 30000 ppm as a short-term exposure limit, i.e., a 15-minutes timeweighted average that should not be exceeded at any time during a workday (NIOSH, 1976; OSHA, 2017).

34. No further information is available.

Safe work Australia

35. Safe work Australia determined workplace exposure standards for CO2 of 5000 ppm (TWA) and 30000 ppm (short-term exposure limit (STEL)).

36. Both are recommended to protect for physiological changes, metabolic stress and asphyxiation in exposed workers (Safe work Australia, 2019).

37. Summaries of data were provided to support the derivation of the TWA and STEL. It was noted that:

- Depending on the duration and concentration, exposure to high concentrations can produce mild narcotic effects, stimulation of the respiratory centre and asphyxiation.
- No noticeable symptoms reported from exposure to 5500 ppm for 6 h.
- Heart rate increase reported in studies with monkeys and apes exposed to concentrations between 7500–40000 ppm at 20–21% oxygen content for 1 h.
- Exposure to 8000–9000 ppm for 24 h associated with alveolar dead space increases in humans.
- Exposure to 8000–12000 ppm for ≤27 d leads to an increase in alveolar partial pressure CO2 and pulmonary ventilation in humans.
- Exposure of 23 men to 15000 ppm for 42 d resulted in physiological adaption and mild evidence of stress reaction; 15000 ppm interpreted as the upper limit of tolerance to extended periods of exposure.
- Exposure to 27600–39500 ppm produced increased pulmonary ventilation rates in short-term exposure, physical exercise studies.
- Slight effect reported in submarine personnel exposed continuously to 30000 ppm with oxygen content maintained at normal concentrations (minimum

18%); complaints of ill effect when oxygen at 15–17%.

- Stimulation of the respiratory centre occurs at 50000 ppm or 5%.
- Exposure to 50000 ppm for 30 min results in signs of intoxication.
- Unconsciousness within a few min at 7–10% (70000–100000 ppm) (ACGIH, 2018; DFG, 1983 as cited in Safe work Australia, 2019).

Scientific Committee on Occupational Exposure Limits (SCOEL)

38. No information is available.

Summary

39. Most aircraft and occupational standards for CO_2 are set at 5000 ppm, and, with the exception of Safe work Australia, no information is available regarding the derivation of this value.

40. Safe work Australia noted that no noticeable symptoms were reported following exposure to 5500 ppm for 6 h and determined a TWA of 5000 ppm. It is uncertain why 5000 ppm rather than 5500 ppm was selected.

Questions on which the views of the Committee are sought

41. Members are invited to consider this paper, and the information in Annex A, and in particular the following questions:

i. What is the Committee's assessment of the potential risks from CO_2 in aircraft cabin air?

IEH Consulting under contract supporting the UK HSA COT Secretariat

March 2023

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List of Abbreviations

AMC	Acceptable means of compliance
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineer

CAA	Civil Aviation Authority
CCAR	Chinese Civil Aviation Regulations
CEN	Committee for Standardization
COT	Committee on Toxicity
CO	Carbon monoxide
CO2	Carbon dioxide
CS	Certification Specifications
DfT	Department for Transport
EASA	European Aviation Safety Authority
FAA	Federal Aviation Agency
FAR	Federal Aviation Regulations
HSE	Health and Safety Executive
IAQ	Indoor air quality
IOELV	Indicative Occupational Exposure Limit Values
JAA	Joint Airworthiness Authority
JAR	Joint Aviation Regulations

NRC	National Research Council
OSH	Occupational health and safety
OSHA	Occupational Safety and Health Administration
NIOSH	National Institute for Occupational Safety and Health
PEL	Permissible Exposure limit
SBS	Sick building syndrome
SCOEL	Scientific Committee on Occupational Exposure Limits
STEL	Short-term exposure limit
TWA	Time weighted average
VOC	Volatile organic compounds
WEL	Workplace exposure limit

TOX/2023/14 Annex A

COT discussion paper TOX/2022/65: Aircraft Cabin Air - Carbon monoxide and carbon dioxide in aircraft cabin air, and associated minutes

Available: COT Meeting: 14th December 2022 | Committee on Toxicity (food.gov.uk)

Secretariat

March 2023

[1] Hamilton T (2004) Letter to British Airline Pilots Association (BALPA) Aircraft Environment Task Group. UK Civil Aviation Authority, London in best and Michaelis 2005.