National Research Council (US) Committee on Air Quality in Passenger Cabins of Commercial Aircraft. The Airliner Cabin Environment and the Health of Passengers and Crew. Washington (DC): National Academies Press (US); 2002.

7 Air-Quality Measurement Techniques and Applications

As discussed in Chapters 3 and 6, many studies have attempted to show a link between aircraft cabin air quality and health effects. Such an association has been difficult to demonstrate, in part because air quality has been measured in only a small portion of aircraft flights and in part because studies have varied considerably in sampling strategy, environmental conditions measured, and measurement methods used. At present, only air temperature and barometric pressure are routinely measured in commercial aircraft cabins, and only the pressure measurements are recorded as part of the flight data. Furthermore, because most flight data recorders retain only data from the most recent 30 min of operation, current recording practices do not permit assessing variations in cabin pressure throughout a flight or, therefore, identifying periods during which partial pressure of oxygen (PO_2) is low.

In this report, *measurement* refers to the quantitative determination of airborne concentration of a contaminant or of air temperature, relative humidity, or pressure with a suitable instrument. *Monitoring* refers to measurement over a relevant period (e.g., the duration of a flight segment) coupled with the creation of a durable record of the data thus obtained. For example, measurement of cabin air pressure and its indication on a display in the cockpit would not be considered monitoring, but recording the measurement as a function of time in a form that can be reviewed and analyzed later would constitute monitoring. *Continuous monitoring* refers to measurement without interruption during the period of interest and the display or recording of results nearly instantaneously. Although practical instruments do not provide truly instantaneous data, they can generate measurements that are averaged over periods of a few seconds to a few minutes and produce a record of consecutive short-term averages that span the entire period of interest. *Integrated monitoring* relies on instruments that collect a sample of air or of a contaminant in air over a longer period (several minutes to more than an hour, depending on instrument design); the resulting concentration is the integrated, or time-weighted average, concentration over the period of sample collection.

Air temperature is measured and controlled in all commercial aircraft for the comfort of passengers and crew and to help provide cooling capacity to maintain appropriate operating temperatures for electronic and mechanical equipment. Because thermal loads are not the same in all parts of the aircraft, control zones are used. Each zone has an independent temperature sensor and adjustable supply of conditioned air. For example, thermal conditioning in the cockpit is controlled separately from that in the passenger cabin, which may be divided into two or more control zones. The latter subdivision helps to minimize longitudinal movement of air in the cabin (Lorengo and Porter 1986; Stevenson 1994; Hunt et al. 1995).

The location of air temperature sensors varies, but the temperature generally appears to be measured in the supply air as it enters a zone. In some instances, the temperature is measured in the cabin or cockpit air after the supplied air mixes with the resident air. Although air temperature is automatically controlled, the set point can be changed by cockpit crew in response to reports of thermal discomfort from cabin occupants. (See Chapter 2 for additional details on temperature control in aircraft).

Barometric pressure in the pressure hull of the fuselage is measured continuously and is under precise control of an automatic system. The supply of compressed air from the environmental control system (ECS) and release of air through an exhaust valve are balanced automatically to maintain cabin pressure. The system is designed to operate so that the pressure difference across the pressure hull does not exceed a specified limit and to ensure that, at least under routine conditions, the barometric pressure in the pressure hull does not fall below a cabin pressure altitude of 2,440 m (8,000 ft) (ASHRAE 1999a). Those two requirements limit the maximal altitude of the aircraft (Stevenson 1994; Hunt et al. 1995; ASHRAE 1999a).

The PO_2 in the cabin is not measured routinely. However, because the aircraft ECS does not alter the fraction of oxygen (O_2) in outside air, and human occupants in a plane do not reduce the O_2 concentration by an amount that is physiologically important, the PO_2 in the cabin will be a fixed fraction of the total pressure (Arnold et al. 2000). (See Chapter 2 for additional details on cabin air pressure.)

The lack of data on cabin air quality other than temperature and pressure during routine and nonroutine operations of aircraft imposes severe limitations on the ability of the Federal Aviation Administration (FAA), the airlines, and their staff to determine the causes of and measures needed to reduce incidents of health effects and complaints from passengers and cabin crew. To investigate the presumed association between cabin air quality and health effects, quantitative assessment of exposures is needed, and this requires systematic and extensive collection and recording of data on numerous characteristics of the aircraft environment. Without such detailed air-quality information derived from flights in which the ECS operates as designed and those in which mechanical problems (e.g., fluid-seal failures) occur, critical evaluation of the link between air quality and complaints or health problems in crew or passengers will be impossible. Accordingly, aircraft measurements should be expanded by incorporating several simple, reliable instrument systems for monitoring relevant characteristics of cabin air quality.

Depending on the program objectives (see Chapter 8), several air-quality characteristics may need to be monitored continuously. The characteristics may include air temperature, pressure, ozone (O_3), carbon monoxide (CO), carbon dioxide (CO_2), relative humidity, and fine particulate matter (PM). Integrated samples of PM may also need to be collected and analyzed to determine the concentration of toxic components of airborne PM.

Techniques used to monitor the characteristics that are not currently monitored on aircraft are discussed in the following sections. The final sections of this chapter address the location of sampling ports, data processing, and the committee's conclusions and recommendations.

OZONE

To meet the FAA O_3 limits, commercial aircraft that fly “high-O_3” routes often use devices to remove O_3 from the cabin supply air. Such devices are usually catalytic converters, but charcoal adsorption has also been used (SAE 1965; Boeing 2000). On planes that use O_3 converters, current practice requires replacing the catalyst infrequently (e.g., once every 2–6 yr depending on model for Boeing aircraft [D.Space, Boeing, personal communication, February 12, 2001] or after about 12,000 flight hours for Airbus aircraft [M. Dechow, Airbus, personal communication, February 9, 2001]). Yet numerous contaminants have the potential to come into contact with and poison the catalyst during daily operations. Real-time O_3 monitoring will indicate whether the catalyst is functioning as intended and will alert crew when maintenance or replacement is required. In fact, the 1986 National Research Council (NRC) committee stated in its report on aircraft air quality: “Because catalytic converters are subject to contamination and loss of efficiency, it is suggested that FAA establish policies for periodic removal and testing, so that the effective life of these units can be established. A program of monitoring is needed, to establish compliance with the existing standard and to determine whether the catalytic converters are operating normally and effectively. These data should be maintained in such a manner that they can be used for reference on passenger and crew exposures to O_3 and to document the concentrations of O_3” (NRC 1986).

Continuous O_3 monitoring would also test the assertion that O_3-removing devices are not necessary on some routes. The available information on O_3 concentrations during different flight segments is far from complete. The present committee understands that O_3-destroying catalysts are most often used on high-altitude polar flights. However, data collected by the National Aeronautics and Space Administration (NASA) in the late 1970s demonstrate that high O_3 can also be encountered on flights at lower latitudes, especially during late winter and early spring (Holdeman et al. 1984). Table 7–1 presents data from nine flights in 1978 chosen to illustrate that fact. The data are based on simultaneous measurements of O_3 in the ambient air and supply air for a United Airlines 747SP, and the reported values are means of all O_3 measurements taken on each flight. For each flight, mean O_3 concentration in the cabin exceeded 0.20 ppm, well in excess of the 1-h national ambient air-quality standard (NAAQS) set by the Environmental Protection Agency (EPA). Furthermore, because the data are means, they do not reveal the magnitude of short-term peak concentrations during the sampled flights. (See Chapter 3 for a detailed discussion of O_3 in aircraft and methods of controlling O_3 in aircraft.)

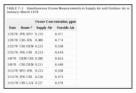

TABLE 7–1 Simultaneous Ozone Measurements in Supply Air and Outdoor Air o
January–March 1978

Date	Route[a]	Ozone Concentration, ppm	
		Supply Air	Outside Air
1/25/78	JFK-SFO	0.215	0.471
1/29/78	CHI-JFK	0.380	0.774
2/22/78	CHI-DEN	0.223	0.538
2/25/78	JFK-CHI	0.233	0.643
3/8/78	DEN-CHI	0.280	0.653
3/8/78	CHI-DEN	0.231	0.440
3/12/78	SFO-JFK	0.233	0.528
3/13/78	JFK-CHI	0.236	0.473
3/15/78	CHI-LAX	0.227	0.570

TABLE 7–1

Simultaneous Ozone Measurements in Supply Air and Outdoor Air on Selected 747 Flights, January–March 1978.

Available Technology

The feasibility of monitoring O_3 in commercial aircraft has been demonstrated in a sampling program launched in 1983 by European scientists called Measurement of Ozone and Water Vapor by Airbus In-Service Aircraft (MOZAIC). Its aim is to measure O_3 and water vapor in the atmosphere by using commercial long-range aircraft. MOZAIC uses fully automatic instruments installed on five long-range Airbus 340 aircraft that are in normal service. The participating carriers are Air France, Sabena, Lufthansa, and Austrian Airlines. By the end of December 1997, 7,500 flights using the instruments had been completed, and 54,000 flight hours of observation had been automatically recorded (Marenco et al. 1998). Although MOZAIC is focused on O_3 outside the aircraft, the same general approach could be used to monitor O_3 and other characteristics inside the aircraft.

The MOZAIC program uses a dual beam ultraviolet-photometric instrument to measure O_3. The instrument monitors the absorbance of O_3 at 254 nm. Similar instrumentation could be used for routine monitoring of O_3 in an aircraft. It is rugged, reliable, accurate, and sufficiently sensitive (about 1 ppb with a 10-cm pathlength). It uses no consumables and holds calibration well. Similar instrumentation was also used in the earlier NASA studies (Holdeman et al. 1984). Given the constraints on instrumentation aboard an aircraft, ultraviolet-photometric monitoring is more readily adapted to this environment than alternative approaches, such as chemiluminescence or electrochemical methods.

Application to Aircraft Cabin

The primary sampling point for measuring O_3 should be in the air supplied to the passenger cabin.[1] Sampling at that location will provide the best indication of the efficacy of the O_3 catalyst and of the worst case for occupant exposure, in that supply air is typically diluted with recirculated air. Furthermore, exposure of the average occupant will be lower because of O_3 decomposition in the cabin. The reading could also be used to alert pilots when the aircraft is passing through air masses that have high O_3 concentrations. Although air masses with high O_3 are probably large, the pilots may be able to seek cleaner air or may temporarily decrease the amount of outdoor air brought into the aircraft. Such readings, archived for a suitable period, would also be useful in evaluating incident complaints from passengers or crew.

A secondary sampling point for supplemental monitoring of O_3 might be in the exhaust air. The aircraft selected for supplemental monitoring would be ones that fly routes with potentially higher O_3. When values measured in the exhaust air are compared with values measured in the supply air, the difference will provide information on the rate of surface removal in the aircraft. Such information is helpful in specifying design requirements for O_3-removing devices. (See Chapter 3 for a discussion of retention ratios in Box 3–2.) Improved knowledge of the magnitude of the surface removal rate would also facilitate calculation of O_3 concentration in the aircraft cabin, given O_3 concentration in the supply air and a known air-exchange rate.

CARBON MONOXIDE

Data from limited research investigations suggest that CO concentrations in aircraft cabin air are generally well below those associated with health effects (Nagda et al. 2000). However, a few reports suggest that operation of aircraft under nonroutine conditions (e.g., when an engine-seal leak permits engine oil or hydraulic fluid to enter bleed air) may lead to the production of CO and contamination of cabin air to concentrations that are associated with health risks (Rayman and McNaughton 1983; van Netten 1998; Pierce et al. 1999; Balouet 2000; van Netten and Leung 2000, 2001).

The acceptable limits for CO in air, as summarized in Table 7–2, vary widely, depending on the organization setting the limit and the population to be protected. The limits set by the National Institute for Occupational Safety and Health (NIOSH), the Occupational Safety and Health Administration (OSHA), and the American Conference of Governmental Industrial Hygienists (ACGIH) are intended for workplace exposures of healthy adults; they are not intended to apply in situations where infants, children, the elderly, or those with pre-existing cardiovascular or pulmonary disease might be exposed. The latter subpopulations are addressed by the EPA NAAQSs.

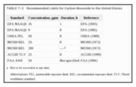

TABLE 7–2 Recommended Limits for Carbon Monoxide in the United States

Standard	Concentration, ppm	Duration, h	Reference
EPA NAAQS	35	1	EPA (1985)
EPA NAAQS	9	8	EPA (1985)
OSHA PEL	50	8	OSHA (1989)
NIOSH REL	35	8	NIOSH (1972)
NIOSH REL	200	—[a]	NIOSH (1972)
ACGIH TLV	25	8	ACGIH (1999)
FAA AWS	50	Not specified	FAA (1996)

a Not to be exceeded at any time.

Abbreviations: PEL, permissible exposure limit; REL, recommended exposure limit; TLV, Thresh
worthiness standard.

TABLE 7–2

Recommended Limits for Carbon Monoxide in the United States.

Available Technology

Portable instruments for continuous monitoring of CO have been in use for several years in buildings and in occupational settings. They use electrochemical sensors that have sufficient accuracy in the range of concentrations of interest (1–100 ppm), and they have been used in a few research investigations aboard aircraft (Nagda et al. 2001). The available CO instruments provide analogue voltage output signals suitable for recording or digital logging by computer. An example is the model 190 CO monitor manufactured by the Draeger Corporation (Woebkenberg and McCammon 1995).

More sophisticated instruments based on nondispersive infrared absorption have also been developed. These instruments have substantially better accuracy and precision than electrochemical methods, but they are much larger, are more expensive, and require larger power supplies. Their superior accuracy and precision might not be warranted for aircraft cabin air monitoring (Parish et al. 1994).

Application to Aircraft Cabin

Because events leading to production of CO in bleed air are likely to be rare, their evaluation would require continuous monitoring and recording of concentrations on a large number of commercial flights. However, a continuous monitor could provide a warning of hazardous conditions in time for appropriate measures to reduce or prevent excessive exposures.

CO monitors should be placed in air supply ducts leading to each of the cabin air ventilation zones. Electrochemical devices can be operated in the active mode, in which a small air pump draws a continuous sample from the air supply ducts to the sensor via flexible tubing, or in the passive mode, in which the sensor is directly in the air stream to be sampled and the CO enters the sensor by diffusion through a semipermeable membrane (Woebkenberg and McCammon 1995).

CARBON DIOXIDE

Except in the case of fire, CO_2 does not pose a health hazard at the concentrations likely to be encountered in commercial aircraft; however, CO_2 is a useful surrogate indicator of substandard ventilation of a space with outside air, as has been shown in numerous studies of building-related symptoms (Cain et al. 1983; Berg-Munch et al. 1986). (See Appendix B for definition and discussion of building-related symptoms.) When fresh-air ventilation is substandard, trace contaminants (e.g., bioeffluents) generated in an occupied space accumulate to concentrations that might trigger complaints from the occupants. Because human occupants are the major source of indoor CO_2, this gas is a useful indicator of the buildup of the trace contaminants generated by humans and human activity.

The recommended upper limit for CO_2 concentration on the basis of health effects is 5,000 ppm as established by OSHA, NIOSH, ACGIH, and FAA. However, much lower limits are required when CO_2 is used as a surrogate for other bioeffluents. In that context, building ventilation guidelines are set so that the indoor CO_2 concentration does not exceed 700 ppm above the concentration in outside air (ASHRAE 1999b), or about 1,100 ppm. Recent evidence suggests that building-related symptoms decrease with decreasing CO_2 even when the CO_2 is below 800 ppm (Seppänen et al. 1999). Accordingly, maintenance of an upper limit of 800–1,000 ppm appears to be necessary to minimize the frequency of complaints of poor air quality from the occupants of a building (Seppänen et al. 1999). However, because the aircraft cabin environment differs substantially from that of buildings (e.g., the occupant density and air exchange rates are much higher in aircraft), the use of indoor air-quality guidelines for CO_2 in air might not be appropriate for commercial aircraft.

Available Technology

Instruments of a size suitable for use in continuous monitoring on aircraft have been developed and used in research investigations (Nagda et al. 2000). They are nondispersive infrared photometers that use light-emitting diodes as the infrared sources. Such instruments have acceptable accuracy for CO_2 concentrations of 100–50,000 ppm (0.01–5% by volume). An example is the Telaire model 7001 instrument manufactured by Englehard Corporation (Woebkenberg and McCammon 1995).

Application to Aircraft Cabin

One or more CO_2 sensors should be placed in the exhaust ducts from the ventilation zones of the aircraft to monitor the effectiveness of fresh-air ventilation to each zone. Effective ventilation depends on the volume of fresh air delivered to the space and the extent to which the incoming air is mixed with the resident air by turbulence and natural convection. Because outside air contains CO_2 at about 370 ppm, any increase in cabin air concentration above this reflects the contribution of interior sources.

The use of dry ice (frozen CO_2) for keeping foods and beverages cool on board aircraft may occasionally lead to difficulty in interpreting continuous-monitoring records of CO_2 concentration. To avoid misinterpretation of data because of interference from sublimation of dry ice, it must first be determined whether air exhausted from the galley is directed overboard and not recirculated.

RELATIVE HUMIDITY

As described in Chapter 2, moist outside air is dehumidified before it is supplied to the cabin to prevent excessive humidity in the cabin. However, when the outside air contains little moisture, as is the case at typical cruise altitudes, air supplied to the passenger cabin is not humidified. The main source of humidity is the occupants (moisture from exhaled air and evaporation of perspiration from skin). Evaporation from food and drinks may also contribute a modest amount of moisture. As explained in Chapter 2, relative humidity is inversely related to the outside-air ventilation rate in this situation.

Relative humidity is not routinely monitored in commercial aircraft, but some measurements have been reported as part of several research investigations involving small numbers of flights. At cruise altitudes, the results of those measurements are consistent with expected humidity and indicate the absence of other major sources of moisture in flight (Arnold et al. 2000; De Ree et al. 2000; Lee et al. 2000; Nagda et al. 2001).

Although low relative humidity has not been associated with increased susceptibility to infection or other health effects, it appears to be related to complaints of irritation of eyes and mucous membranes among passengers and crew (Lindgren et al. 2000). (See Chapter 5 for additional discussion on health effects of low humidity.) Therefore, relative humidity should be monitored during flights so that the relationship between all air-quality characteristics and the health and comfort of passengers and crew can be fully evaluated.

Available Technology

Portable instruments for monitoring relative humidity or dewpoint temperature have been evaluated by several investigators and have been shown to have sufficient accuracy and precision for monitoring relative humidity between 2.5% and 80% (Freitag et al. 1994; Lafarie 1985). The most commonly used methods incorporate a thin hygroscopic polymer film whose electrical capacitance varies with relative humidity or an electrolyte solution whose electrical impedance varies with relative humidity. These instruments have an accuracy of approximately ±2.5% at relative humidity below 80% if calibrated periodically. Newer devices use a surface acoustic wave sensor and have better accuracy and precision (Hoummady et al. 1995), but their added cost may outweigh their greater accuracy.

Application to Aircraft Cabin

As with many of the instruments described above, relative-humidity monitors should be placed so as to sample the air leaving the cabin or cockpit. Because the outside air at cruise altitude contains essentially no moisture, the moisture content of cabin air will provide an indication of the balance between the indoor sources of moisture (e.g., occupants, food, and beverages) and the outside air delivered by the ECS. Air-temperature sensors should be co-located with the relative-humidity sensors so that relative-humidity measurements can be accurately converted to absolute-humidity values needed to complete this evaluation.

PARTICULATE MATTER

Continuous Monitoring for Fine Particles

Fine particles (particles with diameters of approximately 0.2–2.0 µm) are generated by combustion and can indicate nonroutine events, such as the pyrolysis of hydraulic fluids and engine oil that have accidentally entered bleed air. However, the ambient air that enters the cabin can also be a source of fine particles, particularly when the aircraft is on the ground or during takeoff and landing, as can effluents from the galley during meal service. Therefore, correct interpretation of fine-particle measurements will require that they be compared with data on the phase of the flight and the timing of galley activity.

Available Technology

A nephelometer (a continuous monitor of light scattered by suspended fine particles) can be used to monitor air that leaves the passenger cabin and is directed to the recirculation or exhaust system (ACGIH 2001). It would provide a continuous and on-line indication and recording of the mass concentration of fine particles and thus the potential exposure of passengers and cabin attendants to combustion byproducts. Although coarse particles (particles with diameters greater than 2 µm) from resuspended dust on carpets, seats, luggage, and occupants' clothing may also be present in the cabin air, they are less efficient in scattering light and will contribute less than the fine particles, per unit mass, to the measured light scattering.

Several companies manufacture and distribute portable nephelometers that could be used to monitor fine-particle concentrations in aircraft cabins. The most rugged and reliable use light-emitting diodes as light sources and solid-state photodetectors to collect the scattered light from particles passing through the sensing zone (Jensen and O'Brien 1993; Watson and Chow 1993). Some of them also have built-in data loggers that can accumulate and average concentration readings over preselected intervals ranging from seconds to many minutes and can retain several thousand individual measurements for analysis of temporal patterns of concentration. One of the most compact is the MIE Corp. Personal DataRam; another suitable instrument is the Dustrak (TSI Corp.).

Application to Aircraft Cabin

If the sensing zone of a nephelometer is located in the air leaving the passenger cabin, the monitoring system can determine the highest particle concentration in the cabin. Although particles are lost to surfaces in the cabin, the exhausted air contains particles originating from sources that influence supply air and sources in the cabin.

The output signals from the nephelometers should be connected to the aircraft's air-quality data recorder for analysis and correlation with reported health problems. Although the recordings will not provide information on particle composition, the temporal record of particle concentrations throughout the flight—in conjunction with other available data on aircraft system operations, observations in the cabin during the flight, and later physical investigation—may alert crew to nonroutine events and help to identify the nature of a problem.

Integrated Monitoring of Particulate Matter

Although a nephelometer can provide real-time data on particle concentrations throughout a flight segment, it cannot provide information on the chemical or biological composition of the particles. When such information is needed for forensic evaluation of air-quality problems that may have contributed to passenger or crew illnesses or incapacitation, it can be obtained only from PM samples that are collected on filters during the flight and then analyzed with sensitive laboratory techniques.

The collection of such filter samples from the air exhausted from the passenger cabin is relatively simple and inexpensive. However, the analysis of such samples is usually expensive. Such analyses would normally be performed only in the rare cases when poor air quality is considered a likely cause of passenger or crew illness or incapacitation. The occurrence of nonroutine conditions during a flight is an important example in which a record of airborne PM might be valuable. The exposure information could be linked to health data to evaluate the impact of nonroutine operation of the ECS.

Available Technology

Sequential air samplers that collect particles on segments of a continuous filter-tape reel are commercially available. The tape can be advanced at programmed intervals to present a fresh surface for each phase of sampling. The previous samples accumulate on the takeup reel for laboratory analysis as needed. A relatively compact and rugged unit of this type is marketed by MDA, Inc. (ACGIH 2001).

Application to Aircraft Cabin

A modified version of the MDA sequential sampler might be used that advances the filter tape in response to altimeter readings, with operational temporal segments collected for the following flight segments:

- The ground-based phase (boarding of flight crew through aircraft takeoff).

- The interval from takeoff through reaching cruise altitude.
- The interval during flight at cruise altitude.
- The interval covering descent, landing, and taxi to gate.

The filter tapes containing appropriate identification codes for locating specific flight-segment samples should be archived for some period in case a forensic or research investigation is needed. If no air-quality problems are identified and no analyses are needed, the filter tapes could be transferred to long-term storage or discarded.

PESTICIDES

Measurement of exposure to pesticides during and after aircraft disinsection may require air monitoring, as well as other analytic techniques because exposures may occur as a result of surface contamination. For the airborne route, analysis of integrated PM samples for pesticides would provide a measure of exposure to airborne particles resulting from direct spraying or resuspension of settled material. However, the assessment of dermal or oral exposure resulting from contaminated surfaces in the cabin poses considerable difficulty.

The methods available to assess the noninhalation routes include analyzing samples removed from aircraft cabin surfaces and from skin and sampling of body fluids or tissues. Surface measuring techniques have recently been reviewed (Schneider et al. 2000) and consist of hand-washing, surface suction, or surface-wipe sampling followed by analysis of the removed material for the chemical of concern. The removal efficiency of these sampling methods is highly variable, depending on surface characteristics, time since surface deposition, and other factors. Therefore, any application of the methods to aircraft cabin surfaces or to the skin of passengers and crew requires careful prior determination of removal efficiency. None of the few reports of surface sampling of aircraft for pesticides, such as that by Murawski (2001), has included measurements of removal efficiency. It appears that a reliable method for surface monitoring of pesticide exposure is not yet available.

Biological monitoring for pesticide exposure of cabin occupants (e.g., collection and analysis of voided urine after a flight) may be useful. Metabolites of several pyrethroid insecticides can be found in the urine of exposed persons within 24 h of exposure (Lauwerys and Hoet 1993). A more detailed discussion of biological monitoring techniques and their advantages and disadvantages for aircraft occupants is provided in Appendix D.

OTHER MONITORING METHODS

Many other continuous and integrated monitoring techniques have been used to investigate air quality other than that on commercial aircraft. The techniques include analysis for sulfur, phosphorus, volatile organic compounds (VOCs), and semivolatile organic compounds and analysis of human body fluids or tissues to assess systemic exposure. Although their implementation in aircraft has not been demonstrated, and their widespread application might not be technically feasible, their use in selected research applications could be valuable. A more detailed discussion of several techniques is presented in Appendix D.

SAMPLING LOCATIONS

Except for O_3 and CO, the most appropriate location for instrument sampling points is in the cabin or cockpit air outlet ducts. Air at these locations best reflects the mixed concentration in the ventilated space and therefore yields the best indication of the average exposure of passengers and crew. Although drawing samples from the inlet ducts would give a better measure of the quality of the supply air, it does not reflect what the passengers and crew are directly exposed to because supply air is mixed to a variable extent with the resident air in the cabin or cockpit. The committee notes that sampling from points in the air outlet ducts might not provide useful information when aircraft doors are open during loading and unloading because the cabin ventilation system might not be operating.

In some cases, sampling multiple locations in the aircraft may be necessary. For example, in aircraft with separate ventilation zones for cockpit, first-class, and economy sections, multiple sampling points would be needed to give a complete picture of air quality in the occupied spaces. It may also be useful in some cases to sample bleed air or recirculated air after filtration or passage through O_3 or VOC scrubber devices to evaluate their performance.

DATA PROCESSING

Cockpit Indicators

Analogue or digital signals from all or some of the continuous instruments could be displayed in the cockpit. Such displays would be useful in evaluating the performance of the ECS during various flight phases and could also yield early indications of seal failures, fluid leaks, or other problems that could require changes in the flight path or maintenance after landing. Cockpit crew members would need to be trained in evaluation of such signals.

Logging and Storage of Data

To meet the purposes of air-quality monitoring, data from each instrument must be recorded and stored in a form that can be retrieved and examined. Each of the continuous instruments described above provides electronic signals suitable for recording and storage as time-resolved data. Those signals could be added to the flight-data recording system if it has sufficient capacity, or they could be logged with a separate dedicated recorder for analysis during investigations of equipment failure or health complaints from passengers and crew. The following are several examples of potential application of air-quality monitoring:

- Cockpit indicators could alert a pilot to high O_3 concentrations (greater than 0.25 ppm, according to FAR). Logged O_3 data could provide information for maintenance crews on the efficiency of O_3 converters and indicate when such devices should be refurbished or replaced.
- The CO_2 indicator could alert a pilot to conditions under which the air-exchange rate should be increased.
- The CO and nephelometer (PM) data could alert maintenance personnel to leaking fluid seals, especially at cruise, when no other sources of fine particles are expected.

Available Technology

With the exception of integrated PM sampling, each instrument type described above has the ability to sample and analyze air for the target contaminant or property on a time scale of seconds to minutes, so their output can be regarded as "continuous." In the cockpit, these instruments can provide analogue or sometimes digital outputs that are appropriate (Ness 1991). Their signals provide up-to-the-minute data on absolute concentrations, and instrument response is fast enough to permit accurate determination of the rate of change in concentration.

For data recording and storage, relatively few continuous monitors for gaseous chemicals with data-logging capabilities are available, and an external storage device may therefore be needed (Gressel et al. 1988). Such devices are modified computers that collect, store, and deliver data to other computers or display devices. They are available with a wide variety of data capacities and are capable of collecting signals from multiple instruments nearly simultaneously (Ness 1991).

Data stored during a flight should include flight number, date, and continuous data on cabin air characteristics with elapsed time indicated. They could be transferred to an archive file on a larger computer and stored for a selected period.

Figure 7–1 provides an example of continuous monitoring that was conducted on a Boeing 767 aircraft with a 98% load factor and the type of data that can be obtained from sampling instruments (Spengler et al. 1997; Dumyahn et al. 2000). Measurements that were taken throughout the flight from boarding through deplaning included barometric pressure, temperature, relative humidity, and CO_2. The vertical dashed lines indicate the various states of flight: boarding, takeoff, cruise, landing, and deplaning. The horizontal axis indicates the time when concentrations were observed.

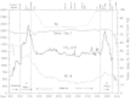

FIGURE 7–1

Environmental conditions on a Boeing 767 with 98% load factor. Event index: D-C (door close), x (taxi), SO (seatbelt off), ON-ST (on seat), OFF-ST (off seat), SON (seatbelt on). Abbreviations: Bp, barometric pressure; RH, relative humidity.

CONCLUSIONS

- Current air-quality measurement practices on commercial aircraft include only indicators of temperature and pressure. These practices are insufficient to determine all cases when the ECS is not working properly or when air-quality incidents occur, and they do not allow evaluation of the possible link between exposures and health effects.
- Although continuous air monitoring has not been implemented, it is technically feasible for a number of air-quality characteristics on commercial aircraft, including temperature, barometric pressure, O_3, CO, CO_2, relative humidity, and fine PM. Collecting filter samples of suspended PM that could be archived for analysis is also feasible.
- Although air-quality monitoring techniques for additional agents, such as pesticides, are available, their applicability to aircraft may require further research and development.

RECOMMENDATIONS

- Instruments for monitoring O_3, CO, CO_2, temperature, cabin pressure, relative humidity, and PM should be used in the surveillance or research investigations aboard commercial aircraft as described in Chapter 8.
- Because of the committee's concern that O_3 can exceed health standards on routine flights that are not expected to encounter high O_3 concentrations, it recommends that FAA take effective measures to ensure that the current FAR for O_3 (i.e., average concentrations not to exceed 0.1 ppm above 27,000 ft, and peak concentrations not to exceed 0.25 ppm above 32,000 ft) is met on all flights, regardless of altitude. These measures should include a requirement that O_3 converters be installed, used, and maintained on all aircraft capable of flying at or above those altitudes, or a requirement that strict operating limits be set with regard to altitudes and routes for aircraft without converters to ensure that the O_3 concentrations are not exceeded in reasonable worst-case scenarios.
- Methods for monitoring additional air-quality characteristics and other measures of cabin-occupant exposure should be investigated as indicated by the data needs.

REFERENCES

ACGIH (American Conference of Governmental Industrial Hygienists). 1999. Documentation of the Threshold Limit Values and Biological Exposure Indices, Sixth Ed. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

ACGIH (American Conference of Governmental Industrial Hygienists). 2001. Air Sampling Instruments for Evaluation of Atmospheric Contaminants, 9th Ed. Cincinnati, OH: American Conference of Governmental Industrial Hygienists. Arnold, K., S.Crha, and L.Patten. 2000. The effect of recirculation on aircraft cabin air quality—In-flight tests and simulation study. Pp. 26–44 in Air Quality and Comfort in Airliner Cabins, N.Nagda, editor. , ed. West Conshohocken, PA: American Society for Testing and Materials.

ASHRAE (American Society of Heating Refrigerating and Air-Conditioning Engineers). 1999. a. Chapter 9 in Aircraft in 1999 ASHRAE Handbook: Heating, Ventilating, and Air- Conditioning Applications. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA.

ASHRAE (American Society of Heating Refrigerating and Air-Conditioning Engineers). 1999. b. ASHRAE Standard—Ventilation for Acceptable Indoor Air Quality. ANSI/ASHRAE62–1999. American Society of Heating Refrigerating and Air-Conditioning Engineers, Atlanta, GA.

Balouet, J. 2000. Letter from J.C.Balouet, Environment International, Nogent/Marne, France to the National Research Council. In-Cabin Airborne Chemicals: A Short List. July 26, 2000.

Berg-Munch, B., G.Clausen, and P.Fanger. 1986. Ventilation requirements for the control of body odor in spaces occupied by women. Environ. Int. 12(1–4):195–200.

Boeing. 2000. Airplanes 201. The Airplane Cabin Environment. Boeing Commercial Airplanes Group, Seattle, WA.

Cain, W., B.P.Leaderer, R.Isseroff, L.G.Berglund, R.J.Huey, E.D.Lipsitt, and D.Perlman. 1983. Ventilation requirements in buildings—I. Control of occupancy odor and tobacco smoke odor. Atmos. Environ. 17(6):1183–1197.

De Ree, H., M.Bagshaw, R.Simons, and R.A.Brown. 2000. Ozone and relative humidity in airline cabins on polar routes: Measurements and physical symptoms. Pp. 243–258 in Air Quality and Comfort in Airliner Cabins, N.Nagda, editor. , ed. West Conshohocken, PA: American Society for Testing and Materials.

Dumyahn, T.S., J.D.Spengler, H.A.Burge, and M.Muilenburg. 2000. Comparison of the environments of transportation vehicles: results of two surveys. Pp. 13–25 in Air Quality and Comfort in Airliner Cabins, N.L.Nagda, editor. , ed. West Conshohocken, PA: American Society for Testing and Materials.

EPA (U.S. Environmental Protection Agency). 1985. National Primary Ambient Air Quality Standards for Carbon Monoxide. 40 CRF 50.8. Fed. Regist. 50(Sept. 13):37501.

FAA (Federal Aviation Regulation). 1996. Part 25. Airworthiness Standards: Transport Category Airplanes. Subpart D- Design and Construction, Ventilation and Heating. Sec. 25.831. Ventilation. Fed. Regist. 61 (Dec. 2):63956.

Freitag, H., Y.Feng, L.Mangum, M.McPhaden, J.Neander, and L.Stratton. 1994. Pp. 1–18 in Calibration Procedures and Instrumental Accuracy Estimates of Tropical Atmosphere Ocean Temperature, Relative Humidity and Radiation Measurements. NOAA Technical Memorandum ERlPMEL 104. Seattle, WA: U.S. Dept. of Commerce, National Atmospheric and Oceanic Administration, Environmental Research Laboratory, Pacific Marine Environmental Laboratory.

Gressel, M.G., W.A.Heitbrink, J.B.McGlothlin, and T.J.Fischbach. 1988. Advantages of real-time data acquisition for exposure assessment. Appl. Ind. Hyg. 3(11):316– 320.

Holdeman, J.D., L.C.Papathakos, G.J.Higgins, and G.D.Nastrom. 1984. Simultaneous Cabin and Ambient Ozone Measurements on two Boeing 747 Airplanes. Vol. II—January to October, 1978. NASA Technical Memorandum 81733 FAA-EE-83– 7. NASA, U.S. Department of Transportation. March 1984.

Hoummady, M., C.Bonjour, J.Collin, F.Lardet-Vieudrin, and G.Martin. 1995. Surface acousting wave (SAW) dew point sensor: Application to dew point hydrometry. Sensors and Actuators B 27(1):315–317.

Hunt, E.H., D.H.Reid, D.R.Space, and F.E.Tilton. 1995. Commercial Airliner Environmental Control System, Engineering Aspects of Cabin Air Quality. Presented atthe Aerospace Medical Association Annual Meeting, Anaheim, CA.

Jensen, P., and D.O'Brien. 1993. Industrial hygiene. Pp. 537–559 in Aerosol Measurement: Principles, Techniques, and Applications, K.Willeke, editor; , and P.Baron, editor. , eds. New York: Wiley.

Lafarie, J.P. 1985. Relative humidity measurement: A review of two state of the art sensors. Pp. 875–889 in Moisture and Humidity 1985: Measurement and Control in Science and Industry. Research Triangle Park, NC: Instrument Society of America.

Lauwerys, R., and P.Hoet. 1993. Industrial Chemical Exposure: Guidelines for Biological Monitoring, 2nd. Ed. Boca Raton, FL: Lewis.

Lee, S.C., C.S.Poon, X.D.Li, F.Luk, M.Chang, and S.Lam. 2000. Air quality measurements on sixteen commercial aircraft. Pp. 45–60 in Air Quality and Comfort in Airliner Cabins, N.Nagda, editor. , ed. West Conshohocken, PA: American Society for Testing and Materials.

Lindgren, T., D.Norback, K.Andersson, and B.G.Dammstrom. 2000. Cabin environment and perception of cabin air quality among commercial aircrew. Aviat. SpaceEnviron. Med. 71(8):774–782. [PubMed: 10954353]

Lorengo, D., and A.Porter. 1986. Aircraft Ventilation Systems Study. Final Report. DTFA-03–84-C-0084. DOT/FAA/CT-TN86/41–I. Federal Aviation Administration, U.S. Department of Transportation. September 1986.

Marenco, A., V.Thouret, P.Nedelec, H.Smit, M.Helten, D.Kley, F.Karcher, P.Simon, K.Law, J.Pyle, G.Poschmann, R.Von Wrede, C.Hume, and T.Cook. 1998. Measurement of ozone and water vapor by Airbus in-service aircraft: The MOZAIC airborne program, an overview. J. Geophys. Res. 103(19):25631–25642.

Murawski, J. 2001. Letter from Judith Murawski, Association of Flight Attendants to Eileen Abt, National Research Council, regarding wipe sample data (permethrin) collected on a recently-sprayed aircraft. March 5, 2001.

Nagda, N.L., H.E.Rector, Z.Li, and E.H.Hunt. 2001. Determine Aircraft Supply Air Contaminants in the Engine Bleed Air Supply System on Commercial Aircraft. ENERGEN Report AS20151. Prepared for American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA, by ENERGEN Consulting, Inc., Germantown, MD. March 2001.

Nagda, N., H.Rector, Z.Li, and D.Space. 2000. Aircraft cabin air quality: A critical review of past monitoring studies. Pp. 215–239 in Air Quality and Comfort in Airliner Cabins, N.Nagda, editor. , ed. West Conshohocken, PA: American Society for Testing and Materials.

Ness, S.A. 1991. Pp. 145–295 in Air Monitoring for Toxic Exposures: An Integrated Approach. New York: Van Nostrand Reinhold.

NIOSH (National Institute for Occupational Safety and Health). 1972. Criteria for a Recommended Standard: Occupational Exposure to Carbon Monoxide. DHEW (HSM) 73–11000. Rockville, MD: U.S. Dept. of Health, Education, and Welfare, Health Services and Mental Health Administration, National Institute for Occupational Safety and Health.

NRC (National Research Council). 1986. The Airliner Cabin Environment: Air Quality and Safety. Washington, DC: National Academy Press.

OSHA (Occupational Safety and Health Administration). 1989. OSHA Regulations, Standards-29 CFR 19100.1000 Air Contaminants, Toxic and Hazardous Substances Final Rule, Table Z-1. Fed. Regist. 54:(Sept. 5)36767. [Online]. Available: http://www.osha-slc.gov/FedReg_osha_data/FED19890905.html [October 18, 2001].

Parish, D.D., J.S.Holloway, and F.C.Fehsenfeld. 1994. Routine continuous measurement of carbon monoxide with parts per billion precision. Environ. Sci. Tech. 28(9):1615–1618. [PubMed: 22176363]

Pierce, W., J.Janczewski, B.Roethlisberger, and M.Janczewski. 1999. Air quality on commercial aircraft. ASHRAE J. (Sept.):26–34.

Rayman, R.B, and G.B.McNaughton. 1983. Smoke/fumes in the cockpit. Aviat. Space Environ. Med. 54(8):738–740. [PubMed: 6626083]

SAE International. (Society of Automotive Engineers International.). 1965. Ozone in High Altitude Aircraft. SAE AIR910. Society of Automotive Engineers International.

Seppanen, O.A., W.J.Fisk, and M.J.Mendell. 1999. Association of ventilation rates and CO2 concentrations with health and other responses in commercial and institutional buildings. Indoor Air 9(4):226–252. [PubMed: 10649857]

Schneider, T., J.W.Cherrie, R.Vermeulen, and H.Kromhout. 2000. Dermal exposure assessment. Ann. Occup. Hyg. 44(7):493–499. [PubMed: 11042250]

Spengler, J., H.Burge, T.Dumyahn, M.Muilenberg, and D.Forester. 1997. Environmental Survey on Aircraft and Ground-Based Commercial Transportation Vehicles. Prepared by Department of Environmental Health, Harvard University School of Public Health, Boston, MA, for Commercial Airplane Group, The Boeing Company, Seattle, WA. May 31, 1997.

Stevenson, G. 1994. Environmental control for aircraft. Pp. 97–101 in World Aerospace Technology '94. London: Sterling.

van Netten, C. 1998. Air quality and health effects associated with the operation of BAe 146–200 aircraft. Appl. Occup. Environ. Hyg. 13(10):733–739.

van Netten, C., and V.Leung. 2000. Comparison of the constituents of two jet engine lubricatin goils and their volatile pyrolytic degradation products. Appl. Occup. Environ. Hyg. 15(3):277–283. [PubMed: 10701290]

van Netten, C., and V.Leung. 2001. Hydraulic fluids and jet engine oils: Pyrolysis and aircraft air quality. Arch. Environ. Health 56(2):181–186. [PubMed: 11339683]

Watson, J., and J.Chow. 1993. Ambient air sampling. Pp. 622–639 in Aerosol Measurement. Principles, Techniques, and Applications, K.Willeke, editor; , and P.Baron, editor. eds. New York: Van Nostrand Reinhold.

Woebkenberg, M.L, and C.S.McCammon. 1995. Direct-reading gas and vapor instruments. Pp. 439–510 in Air Sampling Instruments for Evaluation of Amosperic Contaminants, 8th Ed., B.Cohen, editor; , and S.Hering, editor. , eds. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

Footnotes

1 CFR Section 121.578 “Cabin ozone concentration” states that “no certificate holder may operate an airplane above the following flight levels unless it is successfully demonstrated to the Administrator that the concentration of O_3 inside the cabin will not exceed….” Note that the section does not specify where in the cabin the reading should be taken.

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