Free Executive Summary

The Airliner Cabin Environment and the Health of Passengers and Crew

Committee on Air Quality in Passenger Cabins of Commercial Aircraft, Board on Environmental Studies and Toxicology, National Research Council

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Summary

The number of people traveling by commercial aircraft in recent years is unprecedented. Over the last 30 years, the number of air passengers worldwide has nearly quadrupled, from 383 million in 1970 to 1,462 million in 1998. More older and younger people are flying, including adults with medical conditions (e.g., cardiovascular and pulmonary disease), children, and infants.

The aircraft cabin is similar to other indoor environments, such as homes and offices, in that people are exposed to a mixture of outside and recirculated air. However, the cabin environment is different in many respects—for example, the high occupant density, the inability of occupants to leave at will, and the need for pressurization. In flight, people encounter a combination of environmental factors that includes low humidity, reduced air pressure, and potential exposure to air contaminants, such as ozone (O_3), carbon monoxide (CO), various organic chemicals, and biological agents.

Over the years, passengers and cabin crew (flight attendants) have repeatedly raised questions regarding air quality in the aircraft cabin. In 1986, a committee of the National Research Council (NRC), the principal operating arm of the National Academy of Sciences and the National Academy of Engineering, produced a report requested by Congress titled *The Airliner Cabin Environment: Air Quality and Safety*. That report recommended the elimination of smoking on most domestic airline flights and other actions to address health and safety problems and to obtain better data on cabin air quality. In response, the Federal Aviation Administration (FAA) took several actions, including a ban on smoking on all domestic flights. However, 15 years later, many of the other issues about aircraft cabin air quality have yet to be ade

quately addressed by FAA and the airline industry, and new health questions have been raised by the public and cabin crew.

In response to the unresolved issues, Congress—in the Wendell H.Ford Aviation Investment and Reform Act of the 21st Century, enacted in 2000—directed the FAA to ask the NRC to perform another independent study to assess airborne contaminants in commercial aircraft, to evaluate their toxicity and associated health effects, and to recommend approaches to improve cabin air quality.

THE CHARGE TO THE COMMITTEE

The NRC convened a new committee, the Committee on Air Quality in Passenger Cabins of Commercial Aircraft, which prepared this report. The committee's members were selected for expertise in industrial hygiene, exposure assessment, toxicology, occupational and aerospace medicine, epidemiology, microbiology, aerospace and environmental engineering, air monitoring, ventilation and airflow modeling, and environmental chemistry. The committee was charged to address the following topics:

1. Contaminants of concern, including pathogens and substances that are used in the maintenance, operation, or treatment of aircraft, including seasonal fuels and deicing fluids.
2. The systems of passenger cabin air supply on aircraft and ways in which contaminants might enter such systems.
3. The toxic effects of the contaminants of concern, their byproducts, the products of their degradation, and other factors, such as temperature and relative humidity, that might influence health effects.
4. Measurements of the contaminants of concern in the air of passenger cabins during domestic and foreign air transportation and comparison with measurements in public buildings, including airports.
5. Potential approaches to improve cabin air quality, including the introduction of an alternative supply of air for the aircraft passengers and crew to replace bleed air.

The committee was not asked or constituted to address the possible effects of ionizing and nonionizing radiation. Furthermore, the committee did not, nor was it asked to, evaluate the potential costs of implementing any of its recommendations.

THE COMMITTEE'S APPROACH TO ITS CHARGE

The committee heard, in public session, presentations from FAA, the Association of Flight Attendants (AFA), the National Institute for Occupational Safety and Health, the International Association of Machinists and Aerospace Workers (IAM), manufacturers of aircraft and aircraft equipment (Boeing, Airbus, and Honeywell), and consulting firms (Consolidated Safety Services, Inc., and Information Overload Corporation). The committee evaluated the body of literature on air quality in commercial aircraft, emphasizing studies conducted since the 1986 NRC report. It also solicited information from FAA, airlines, aircraft and engine manufacturers, AFA, IAM, and manufacturers of engine lubricating oils and hydraulic fluids. Committee members visited United Airlines heavy maintenance facilities in Oakland, California, and Indianapolis, Indiana.

In addressing its charge, the committee focused on air quality in aircraft regulated by the FAA, on national and international flights. It did not focus on specific types or models of aircraft, but rather examined air quality in commer-cial aircraft in general. Various aircraft models might differ in cabin air quality, but the committee considered the exposure and health-related issues to be applicable to most commercial aircraft systems.

THE COMMITTEE'S EVALUATION

Aircraft Systems

Commercial jet aircraft operate in an external environment that varies widely in temperature, air pressure, and relative humidity as they move from taxiing and takeoff through cruise to descent and landing. To transport passengers and crew through environmental extremes, an aircraft is equipped with an environmental control system (ECS) designed to maintain a safe, healthful, and comfortable environment for the passengers and crew. The air provided to the passengers and crew on jet aircraft is typically a combination of outside air brought in through the engines and air that is taken from the cabin, filtered, and recirculated. The ECS is designed to minimize the introduction of harmful contaminants into the cabin and to control cabin pressure, ventilation, temperature, and humidity.

To promote safe and healthful air aboard commercial aircraft, FAA has established design and operational specifications—Federal Aviation Regulations (FARs) in 14 CFR 21, 14 CFR 25, 14 CFR 121, and 14 CFR 125—for O_3, CO, carbon dioxide (CO_2), ventilation, and cabin pressure.

After reviewing the role and function of the ECS on most aircraft, the committee concluded that the ECS, when operated as specified by the manufacturer, should provide an ample supply of air to pressurize the cabin, meet general comfort conditions, and dilute or otherwise reduce normally occurring odors, heat, and contaminants. The committee noted, however, that the current design standard of a minimum of 0.55 lb of outside air per minute per occupant (FAR 25.831) is less than one-half to two-thirds the ventilation rate recommended in American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 62–1999, which was developed for building environments. Whether the building ventilation standard is appropriate for the aircraft cabin environment has not been established.

Exposures on Aircraft

Although the ECS is designed to minimize the concentrations of contaminants in the cabin, contaminant exposures do occur. They can originate outside the aircraft, inside the aircraft, and in the ECS itself. There are two distinct types of contaminant exposures: those which occur under routine operating conditions and those which occur under abnormal operating conditions. Contaminant exposures that occur under routine conditions include odors and gases emitted by passengers, O_3 that enters with ventilation air during high-altitude cruise, organic compounds emitted from residual cleaning materials and other materials in the cabin, and infectious agents, allergens, irritants, and toxicants. During nonroutine events, contaminant exposures result from the intake of chemical contaminants (e.g., engine lubricating oils, hydraulic fluids, deicing fluids, and their degradation products) into the ECS and then into the cabin.

A number of studies have attempted to collect data on occupant exposures to air contaminants in aircraft cabins under routine conditions. The data represent only a small number of flights, and the studies have varied considerably in their sampling strategies, the environmental factors monitored, and the measurement methods used. Consequently, cabin air quality under routine conditions has not been well characterized. Furthermore, no published studies describe quantitative measurements of air quality under abnormal operating conditions.

Exposures to contaminants that originate outside the aircraft differ, depending on whether the aircraft is on the ground, in ascent, in cruise, or in descent. When the aircraft is on the ground, exposures to outdoor air pollutants (e.g., O_3, CO, and particulate matter) are determined primarily by the ambient concentrations at the airport. During cruise at high altitudes, O_3 concentrations are elevated in ambient air. Although the FAA requires that O_3 concentrations in the aircraft cabin be maintained within specified limits, studies indicate that cabin O_3 concentrations on some flights may exceed the FAA regulatory standards and the Environmental Protection Agency national ambient (outdoor) air standards.

Passengers and crew themselves are the sources of several contaminants (e.g., bioeffluents, viruses, bacteria, allergens, and fungal spores) that originate in the cabin. Furthermore, structural components of the aircraft, luggage, personal articles, animals brought on board, food, and sanitation fluids can be sources of vapors or particles. Cabin surfaces can be sources of residues of cleaning compounds, pesticides, and dust. Passengers and crew have raised questions about exposure to pesticides (e.g., *d*-phenothrin and permethrin), because they are sprayed on selected international flights to limit the spread of insect pests, but no quantitative data are available on passenger or crew exposures to these compounds.

The ECS can be a source of contamination. Problems arise when engine lubricating oils, hydraulic fluids, or deicing fluids unintentionally enter the cabin through the air-supply system from the engines in what is called bleed air. Many cabin crews and passengers have reported incidents of smoke or odors in the cabin. No exposure data are available to identify the contaminants in cabin air during air-quality incidents, but laboratory studies suggest that many compounds are released when the fluids mentioned above are heated to the high temperatures that occur in the bleed-air system.

Health Considerations

Available exposure information suggests that environmental factors, including air contaminants, can be responsible for some of the numerous complaints of acute and chronic health effects in cabin crew and passengers. The complaints tend to be so broad and nonspecific and can have so many causes that it is difficult to define or discern a precise illness or syndrome. The current data collection systems administered by the National Air and Space Administration and AFA, designed to report health complaints of cabin crew and passengers, do not have standardized, systematic methods to collect and record these reports. Furthermore, FAA does not collect health-effects data. Therefore, establishing a causal relationship between cabin air quality and the health complaints of cabin crew and passengers is extremely difficult.

Among the possible causes of the symptoms reported by passengers and cabin crew are the cabin environment itself (e.g., cabin pressure and relative humidity), contaminants (e.g., O_3, pesticides, biological agents, and constituents and degradation products of engine lubricating oils and hydraulic fluids), physiological stressors (e.g., fatigue, cramped seats, and jet lag), and exacerbation of pre-existing conditions in sensitive groups.

Regarding the flight environment, the committee identified two cabin air-quality characteristics that should be given high priority for further investigation: reduced oxygen partial pressure and elevated O_3 concentrations. Although reduced oxygen partial pressure in the aircraft cabin at cruise altitude should not affect healthy people adversely, health-compromised people, particularly those with cardiopulmonary disease, might experience a variety of symptoms. Infants could also be adversely affected because of their greater oxygen requirements. Elevated O_3 concentrations have been associated with airway irritation, decreased lung function, exacerbation of asthma, and impairments of the immune system.

The presence of some biological agents in cabin air, primarily airborne allergens, has also raised questions. Exposures to allergens (e.g., cat dander) have been reported to cause health effects, but have not been definitively documented in aircraft. Transmission of infectious agents from person to person has been documented to occur in aircraft, but the most important transmission factors appear to be high occupant density and the proximity of passengers. Transmission does not appear to be facilitated by aircraft ventilation systems.

Other cabin air contaminants or characteristics during routine operations are generally not expected to cause adverse health effects. One possible exception is the low relative humidity that occurs on nearly all flights. Low relative humidity might cause some temporary discomfort (e.g., drying of the eyes, nose, and skin) in cabin occupants; its role in causing or exacerbating short- or long-term health effects has not been established. Another possible exception is exposure to pesticides that are applied on some international flights; these chemicals can cause skin irritation and are reported to be neurotoxic, although of low toxicity in humans.

During abnormal operating conditions, exposure to several contaminants might occur. The engine lubricating oils and hydraulic fluids used in commercial aircraft are composed of a variety of organic constituents, including tricresyl phosphate, a known neurotoxicant. If the oils and fluids and their potential degradation products (e.g., CO and formaldehyde) enter the aircraft cabin, they will adversely affect cabin air quality. No data have definitively linked exposure to these compounds with reported health effects in cabin occupants.

Findings

The primary air-quality characteristics evaluated by the committee are summarized in Table S-1, which presents information on potential health effects, frequency of occurrence, and quality of the available data. The committee ranked the characteristics as of low, moderate, or high concern, on the basis of the likelihood of exposure and the potential severity of their effect. For example, hydraulic fluids or engine lubricating oils were ranked as of moderate concern because the potential severity of their effects is high but the likelihood of exposure to them at high concentrations is believed to be low. An important point to note is that the ability to evaluate a characteristic is limited in most cases because of a lack of data on exposure or health effects.

RECOMMENDATIONS

1. FAA should rigorously demonstrate in public reports the adequacy of current and proposed FARs related to cabin air quality and should provide quantitative evidence and rationales to support sections of the FARs that establish air-quality-related design and operational standards for aircraft (standards for CO, CO_2, O_3, ventilation, and cabin pressure). If a specific standard is found to be inadequate to protect the health and ensure the comfort of passengers and crew, FAA should revise it. For ventilation, the committee recommends that an operational standard consistent with the design standard be established.
2. FAA should take effective measures to ensure that the current FAR for O_3 (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 either O_3 converters be installed, used, and maintained on all aircraft

TABLE S-1 Air-Quality Characteristics: Potential Health Impacts and Likelihood of Exposure

Characteristic[a]	Potential Health Impacts	Frequency of Exposure	Availability of Information
High Concern			
Cabin pressure	Serious health effects may occur in some people (e.g., infants and those with cardiorespiratory diseases) due to decreased oxygen pressure. Temporary pain or discomfort due to gas expansion (e.g., middle ear or sinuses) may occur.	Reduced cabin pressure occurs on nearly all flights.	Reliable measurements are available; health effects in some sensitive groups are uncertain.
Ozone	Health effects (e.g., airway irritation and reduced lung function) may occur at concentrations as low as 0.1 ppm with increasing severity at higher concentrations, exposure durations, and respiratory rates.	Elevated concentrations are expected primarily on aircraft without O_3 converters that fly at high altitudes; substantial uncertainty exists as to frequency and duration of elevated concentrations on these flights.	Few systematic measurements made since the 1986 NRC report.
Moderate Concern			
Airborne allergens	Inhalation can result in irritated eyes and nose, sinusitis, acute exacerbations of asthma, or anaphylaxis.	Frequency and intensity of exposure sufficient to cause sensitization or symptoms is not known.	Few exposure data are available; only self-reported information on hypersensitivity responses is available.
Carbon monoxide	Headaches and lightheadedness occur at low concentrations; more severe health effects result from higher concentrations and longer durations.	High concentrations could occur during air-quality incidents. Frequency of incidents is highly uncertain, but believed to be low.	Reliable measurements are available for normal operating conditions; no data are available for incidents.

Hydraulic fluids or engine oils (constituents or degradation products)	Mild to severe health effects can result from exposure to these fluids or their degradation products.	Frequency of incidents in which these fluids or degradation products enter the cabin is very uncertain, but is expected to be relatively low.	No quantitative exposure data are available. Little information is available on health effects related to smoke, mists, or odors in aircraft cabin.
Infectious agents	Exposure may have no effect or cause an infection with or without symptoms.	Presence of some infectious agent is likely, but the frequency of exposures that result in infection is not known.	Little information is available on the transmission of infectious agents on aircraft.
Pesticides	Health effects (e.g., skin rashes) can result from dermal or inhalation exposure.	Exposure is likely on selected aircraft used for international flights.	No exposure data are available; only self-reported information on health effects is available.
Low Concern			
Carbon dioxide	Indicator of ventilation adequacy. Elevated concentrations are associated with increased perceptions of poor air quality.	Concentrations are generally below FAA regulatory limits.	Reliable measurements are available only for normal operating conditions.
Deicing fluids	Health effects can result from inhalation of high concentrations.	Frequency is expected to be very low.	No information is available on incidences of fluids entering aircraft.
Nuisance odors	Annoyance and mucosal irritation can occur.	Can be present on any flight.	Reliable information is available from surveys of cabin occupants.
Relative humidity	Temporary drying of skin, eyes, and mucous membranes can occur at low relative humidity (10 to 20%).	Low relative humidity occurs on most flights.	Reliable and accurate measurements in aircraft are available.

[a] Listing in each concern group is alphabetical; the committee did not rank the characteristics within a group.

capable of flying at or above those altitudes, or 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. To ensure compliance with the O_3 requirements, FAA should conduct monitoring to verify that the O_3 controls are operating properly (see also recommendation 8).

3. FAA should investigate and publicly report on the need for and feasibility of installing air-cleaning equipment for removing particles and vapors from the air supplied by the ECS on all aircraft to prevent or minimize the introduction of contaminants into the passenger cabin during ground operation, normal flight, and air-quality incidents.
4. FAA should require a CO monitor in the air supply ducts to passenger cabins and establish standard operating procedures for responding to elevated CO concentrations.
5. Because of the potential for serious health effects related to exposures of sensitive people to allergens, the need to prohibit transport of small animals in aircraft cabins should be investigated, and cabin crews should be trained to recognize and respond to severe, potentially life-threatening responses (e.g., anaphylaxis, severe asthma attacks) that hypersensitive people might experience because of exposure to airborne allergens.
6. Increased efforts should be made to provide cabin crew, passengers, and health professionals with information on health issues related to air travel. To that end, FAA and the airlines should work with such organizations as the American Medical Association and the Aerospace Medical Association to improve health professionals' awareness of the need to advise patients on the potential risks of flying, including risks associated with decreased cabin pressure, flying with active infections, increased susceptibility to infection, or hypersensitivity.
7. The committee reiterates the recommendation of the 1986 NRC report that a regulation be established to require removal of passengers from an aircraft within 30 minutes after a ventilation failure or shutdown on the ground and to ensure the maintenance of full ventilation whenever on-board or ground-based air conditioning is available.
8. To be consistent with FAA's mission to promote aviation safety, an air-quality and health-surveillance program should be established. The objectives and approaches of this program are summarized in Table S-2. The health and air-quality components should be coordinated so that the data are collected in a manner that allows analysis of the suggested relationship between health effects or complaints and cabin air quality.

9. To answer specific questions about cabin air quality, a research program should be established (see Table S-2). The committee considers the following research questions to be of high priority:

   - *O_3.* How is the O_3 concentration in the cabin environment affected by various factors (e.g., ambient concentrations, reaction with surfaces, the presence and effectiveness of catalytic converters), and what is the relationship between cabin O_3 concentrations and health effects on cabin occupants?
   - *Cabin pressure and oxygen partial pressure.* What is the effect of cabin pressure altitude on susceptible cabin occupants, including infants, pregnant women, and people with cardiovascular disease?
   - *Outside-air ventilation.* Does the ECS provide sufficient quantity and distribution of outside air to meet the FAA regulatory requirements (FAR 25.831), and to what extent is cabin ventilation associated with complaints from passengers and cabin crew? Can it be verified that infectious-disease agents are transmitted primarily between people in close proximity? Does recirculation of cabin air increase cabin occupants' risk of exposure?
   - *Air-quality incidents.* What is the toxicity of the constituents or degradation products of engine lubricating oils, hydraulic fluids, and deicing fluids, and is there a relationship between exposures to them and reported health effects on cabin crew? How are these oils, fluids, and degradation products distributed from the engines into the ECS and throughout the cabin environment?
   - *Pesticide exposure.* What are the magnitudes of exposures to pesticides in aircraft cabins, and what is the relationship between the exposures and reported symptoms?
   - *Relative humidity.* What is the contribution of low relative humidity to the perception of dryness, and do other factors cause or contribute to the irritation associated with the dry cabin environment during flight?

10. The committee recommends that Congress designate a lead federal agency and provide sufficient funds to conduct or direct the research program proposed in recommendation 9, which is aimed at filling major knowledge gaps identified in this report. An independent advisory committee with appropriate scientific, medical, and engineering expertise should be formed to oversee the research program to ensure that its objectives are met and the results publicly disseminated.

TABLE S-2 Surveillance and Research Programs

Surveillance Program	Research Program
Objectives	
• To determine aircraft compliance with existing FARs for air quality	• To investigate possible association between specific air-quality characteristics and health effects or complaints
• To characterize accurately air quality and establish temporal trends of air-quality characteristics in a broad sample of representative aircraft	• To evaluate the physical and chemical factors affecting specific air-quality characteristics in aircraft cabins
• To estimate the frequency of nonroutine operations in which serious degradation of cabin air quality occurs	• To determine whether FARs for air quality are adequate to protect health and ensure comfort of passengers and crew
• To document systematically health effects or complaints of passengers and crew related to routine conditions of flight or air-quality incidents; to be effective, this effort must be conducted and coordinated in conjunction with air-quality monitoring	• To determine exposure to selected contaminants (e.g., constituents of engine oils and hydraulic fluids, their degradation products, and pesticides) and establish their potential toxicity more fully
Approach	
• Continuously monitor and record O_3, CO, CO_2, fine particles, cabin pressure, temperature, and relative humidity	• Use continuous monitoring data from surveillance program when possible
• Sample a representative number of flights over a period of 1–2 years	• Monitor additional air-quality characteristics on selected flights as necessary (e.g., integrated particulate-matter sampling to assess exposure to selected contaminants)

• Continue to monitor flights to ensure accurate characterization of air quality as new aircraft come online and aircraft equipment ages or is upgraded	• Identify and monitor “problem” aircraft and review maintenance and repair records to evaluate issues associated with air-quality incidents
• Conduct a program for the systematic collection, analysis, and reporting of health data with the cabin crew as the primary study group	• Collect selected health data (e.g., pulse-oximetry data to assess arterial O_2 saturation of passengers and crew) • Conduct laboratory and other ground-based studies to characterize air distribution and circulation and contaminant generation, transport, and degradation in the cabin and the ECS

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Preface

In 1986, a committee of the National Research Council (NRC), the principal operating arm of the National Academy of Sciences and the National Academy of Engineering, produced a report requested by Congress titled *The Airliner Cabin Environment: Air Quality and Safety*. That report recommended the elimination of smoking on most domestic airline flights and a number of other actions to address health and safety problems and to obtain better data on cabin air quality. In response to that report, the Federal Aviation Administration (FAA) took several actions, including the banning of smoking on all domestic flights. However, the health complaints of passengers and cabin crew continue. Their complaints tend to be broad and nonspecific and to have multiple possible causes, including air contaminants, so it is difficult to define or discern a precise illness or syndrome.

As a result of continued concerns about aircraft cabin air quality and health issues raised by passengers and cabin crew, Congress directed FAA in the Wendell H.Ford Aviation Investment and Reform Act of the 21st Century, enacted in 2000, to request that the NRC perform another independent study to examine cabin air quality.

In this report, the Committee on Air Quality in Passenger Cabins of Commercial Aircraft reviews what is known about air quality in passenger cabins, emphasizing studies conducted since the 1986 report. The committee specifically examined the aircraft environmental control systems, the sources of contaminants in aircraft cabins, and the toxicity and health effects associated with these contaminants; it provides a number of recommendations for potential approaches for improving cabin air quality.

This report has been reviewed in draft form by persons chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purposes of this independent review were to provide candid and critical comments to assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards of objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following for their review of this report: Charles E.Becker (emeritus), University of California, San Francisco School of Medicine, Snow Mass Village, Colorado; Franklin D.Farrington, Boeing Company, Long Beach, California; Ashok Gadgil, Lawrence Berkeley National Laboratory, Berkeley, California; R.Richard Heppe (retired), California Lockheed, Solvang, California; Donald F.Hornig (emeritus), Brown University, Little Compton, Rhode Island; Nadia S.Juzych, Michigan Public Health Institute, Birmingham, Michigan; Roger O.McClellan (emeritus), Chemical Industry Institute of Toxicology, Albuquerque, New Mexico; James M.Melius, New York State Laborers' Health and Safety Trust Fund, Albany, New York; Shelly Miller, University of Colorado, Boulder, Colorado; Niren L.Nagda, Energen Consulting, Inc., Germantown, Maryland; P.Barry Ryan, Emory University, Atlanta, Georgia; John C.Sagebiel, Desert Research Institute, Reno, Nevada; Calvin C.Willhite, California Environmental Protection Agency, Berkeley, California.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of the report was overseen by John C.Bailar, III (emeritus), University of Chicago, Chicago, Illinois, and Edward C.Bishop, Parsons Engineering Science, Inc., Fairfax, Virginia. Appointed by the NRC, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of the report rests entirely with the author committee and the institution.

The committee gratefully acknowledges the following for making presentations to the committee: Charles Ruehle and Thomas Nagle, FAA; Martha Waters, Elizabeth Whelan, and Kevin Dunn, National Institute for Occupational Safety and Health; Christopher Witkowski and Judith Murawski, Association of Flight Attendants; Olney Anthony, International Association of Ma chinists Union and Aerospace Workers (IAM); David Space and Richard Johnson, Boeing Corporation; Martin Dechow, Airbus Corporation; Richard Fox and George Rusch, Honeywell Corporation; Raynard Fenster, Information Overload Corporation; and Jolanda Janczewski, Consolidated Safety Services, Inc. The committee also wishes to thank the following who provided further background information: Gene Kirkendahl and Stephen Happenny, FAA; Ron Shepard, IAM; Jim McClendon, Alaska Airlines; John Downey, BAE Systems; Mac Cookson, Steve Ramdeen, and Kilisi Vailu'u, United Airlines; Sarah Knife, General Electric Aircraft Engines; Keith Morgan, Pratt & Whitney; Wayne Daughtrey, ExxonMobil Corporation; Vincent Johnston, Boeing Corporation; and Robert Wright, U.S. Air Force. The committee gives special thanks to staff at United Airlines who provided site visits of its major maintenance facilities in Oakland, California, and Indianapolis, Indiana, and provided us with additional background information: Clayton Satterlee, Yvonne Daverin, John Upchurch, Anita Davis, Roger Rube, Robert Patterson, Steve Lewis, and Rick Ransom.

The committee is thankful for the useful input of Charles Schumann in the early deliberations of this study. The committee is also grateful for the assistance of the NRC staff in preparing this report. Staff members who contributed to this effort are Eileen Abt, project director; Roberta Wedge, senior program officer; Ellen Mantus, program officer; Norman Grossblatt, editor; Ruth Crossgrove, managing editor; Lucy Fusco, senior project assistant; Mirsada Karalic-Loncarevic, research assistant; and Bryan Shipley, project assistant. I would also like to thank all the members of the committee for their dedicated efforts throughout the development of this report.

Finally, the committee extends its heartfelt condolences to those who lost family, friends, and colleagues in the events of September 11, 2001. These events will undoubtably have extensive repercussions on all aspects of air transportation. Although safety is always the overriding priority for air transportation, air quality in the aircraft cabin will also continue to be an important factor affecting the health of passengers and crew. The committee hopes that this report will make a long-lasting contribution to the goal of ensuring the health of all who fly aboard commercial aircraft.

Morton Lippmann, *Chair*
Committee on Air Quality in Passenger
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