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GAO

Report to the Ranking Democratic Member, Subcommittee on Aviation, Committee on Transportation and Infrastructure, House of Representatives

January 2004

AVIATION SAFETY

More Research Needed on the Effects of Air Quality on Airliner Cabin Occupants

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Highlights

Highlights of GAO-04-54, a report to the Ranking Democratic Member, Subcommittee on Aviation, Committee on Transportation and Infrastructure, House of Representatives

Why GAO Did This Study

Over the years, the traveling public, flight attendants, and the medical community have raised questions about how airliner cabin air quality contributes to health effects, such as upper respiratory infections. Interest in cabin air quality grew in 2003 when a small number of severe acute respiratory syndrome (SARS) infections may have occurred on board aircraft serving areas that were experiencing outbreaks of the disease. In 2001, a National Research Council report on airliner cabin air quality and associated health effects recommended that additional research be done on the potential health effects of cabin air.

GAO reviewed what is known about the health effects of cabin air, the status of actions recommended in the 2001 National Research Council report, and whether available technologies should be required to improve cabin air quality.

What GAO Recommends

GAO recommends that FAA develop detailed plans for its research and surveillance program on cabin air quality, improve the public's access to information on the health risks of flying, and assess the costs and benefits of requiring HEPA filters in commercial aircraft.

www.gao.gov/cgi-bin/getrpt?GAO-04-54.

To view the full product, including the scope and methodology, click on the link above. For more information, contact Gerald L. Dillingham at (202) 512-2834 or dillinghamg@gao.gov.

January 2004

AVIATION SAFETY

More Research Needed on the Effects of Air Quality on Airliner Cabin Occupants

What GAO Found

Despite a number of studies of the air contaminants that airline passengers and flight attendants are potentially exposed to, little is known about their associated health effects. Reports on airliner cabin air quality published by the National Research Council in 1986 and 2001 concluded that more research was needed to determine the nature and extent of health effects on passengers and cabin crew. Although significant improvements have been made to aircraft ventilation systems, cabin occupants are still exposed to allergens and infectious agents, airflow rates that are lower than those in buildings, and air pressures and humidity levels that are lower than those normally present at or near sea level.

The 2001 National Research Council report on airliner cabin air quality made 10 recommendations, 9 of which directed the Federal Aviation Administration (FAA) to collect more data on the potential health effects of cabin air and to review the adequacy of its standards for cabin air quality. FAA has addressed these 9 recommendations to varying degrees as it attempts to balance the need for more research on cabin air with other research priorities (e.g., passenger safety). However, some in the aviation community, including some of the committee members who produced the report on cabin air, do not feel that FAA's planned actions will address these recommendations adequately. For example, most members were concerned that FAA's plan for implementing the report's key recommendations on the need for more comprehensive research on the health effects of cabin air was too limited. FAA plans to address these recommendations in two parts—the first, which started in December 2003, and the second, which will start in December 2004 and end in late 2006 or early 2007. However, FAA lacks a comprehensive plan, including key milestones and funding needs. In addition, most committee members thought that FAA's response to a recommendation for it to improve public access to information on the health risks of flying was inadequate. We also had difficulty accessing this information on FAA's Web site.

Several technologies are available today that could improve cabin air quality, (e.g., increasing cabin humidity and pressure or absorbing more cabin odors and gasses); however, opinions vary on whether FAA should require aircraft manufacturers and airlines to use these technologies. GAO found that one available technology, high-efficiency particulate air (HEPA) filtering, was strongly endorsed by cabin air quality and health experts as the best way to protect cabin occupants' health from viruses and bacteria in recirculated cabin air. While FAA does not require the use of these filters, GAO's survey of major U.S. air carriers found that 85 percent of large commercial airliners in their fleets that recirculate cabin air and carry more than 100 passengers already use these filters. However, the use of HEPA filters in smaller commercial aircraft that carry fewer than 100 passengers is much lower. The cost to retrofit the smaller aircraft to accept the HEPA filter, if it were made mandatory, could be expensive.

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Abbreviations

AFA	Association of Flight Attendants
APFA	Association of Professional Flight Attendants
APL	Applied Physics Laboratory (Johns Hopkins University)
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
AsMA	Aerospace Medical Association
ATA	Air Transport Association
ATR	Avions de Transport Regional
BAe	British Aerospace
BRE	Building Research Establishment
CAA	Civil Aviation Authority (United Kingdom)
CDC	Centers for Disease Control and Prevention
CO	carbon monoxide
CO_2	carbon dioxide
DOT	Department of Transportation
ECS	Environmental Control System
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FARS	Federal Aviation Regulations
GAO	General Accounting Office
HEPA	high-efficiency particulate air
IAPA	International Airline Passengers Association
IATA	International Air Transport Association
JAA	European Joint Aviation Authorities
NEJM	New England Journal of Medicine
NIOSH	National Institute for Occupational Safety and Health
NRC	National Research Council
O_3	ozone
RPM	revenue passenger mile
SARS	severe acute respiratory syndrome
TB	tuberculosis
URI	upper respiratory tract infection
WHO	World Health Organization

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Accountability * Integrity * Reliability

United States General Accounting Office
Washington, D.C. 20548

January 16, 2004

The Honorable Peter DeFazio
Ranking Democratic Member
Subcommittee on Aviation
Committee on Transportation and Infrastructure
House of Representatives

Dear Mr. DeFazio:

The quality of air in commercial airliner cabins has long been a concern of the traveling public, the medical community, and particularly flight attendants, who fly often. Air quality, in the context of airliner cabins, refers to the extent to which airflow, low humidity, and air pressure[1] and contaminants such as pollutants and infectious disease pathogens affect the healthfulness of the air. Air travelers, flight attendants, and the medical community have raised questions about the extent to which cabin air contributes to discomfort, such as dry eyes and nose, and to more serious health effects, such as upper respiratory infections. Interest in cabin air quality heightened in 2003, with reports that a small number of severe acute respiratory syndrome (SARS) infections may have occurred on board aircraft serving areas with SARS outbreaks.[2] In 2001, the National Research Council[3] issued a report that assessed airborne contaminants in commercial aircraft, including an evaluation of their toxicity and associated health effects; addressed cabin pressure (oxygen supply) and ventilation; and recommended approaches to improving data on cabin air quality.[4]

[1]Although airliners are pressurized, the air pressure in an aircraft cabin is lower than it is at sea level. Airliners are required to be pressurized to an altitude that is not higher than 8,000 feet. This is about three-fourths the air pressure at sea level.

[2]According to the World Health Organization (WHO), there is a very low risk of catching SARS through an airplane's ventilation system. SARS is believed to be transmitted based on proximity to an infected individual. However, WHO reported that as of May 23, 2003, there were 29 probable cases of in-flight SARS transmissions on four flights. See appendix III for more information on SARS.

[3]The National Research Council is the principal operating arm of the National Academy of Sciences and the National Academy of Engineering.

[4]National Research Council. *The Airliner Cabin Environment and the Health of Passengers and Crew*, National Academy Press (Washington, D.C.: Distributed electronically December 2001; bound report copyrighted 2002).

Given this backdrop, you asked us to provide information on steps that the aviation community is taking to address concerns about cabin air quality. Specifically, you asked us to address the following questions: (1) What is known about the major potential health effects of air quality in commercial airliner cabins on passengers and flight attendants? (2) What actions has the National Research Council recommended to improve cabin air quality, and what is the status of those actions? (3) What technologies are available today to improve the air quality in commercial airliner cabins, and which, if any, should be required?

To address these questions we reviewed the December 2001 National Research Council report on airliner cabin air quality because it was the most current and comprehensive work of its kind in this area. The Council is the principal operating agency of the National Academy of Sciences, which was chartered by Congress to advise the federal government on scientific and technical matters. To produce the report, the Council convened a committee of experts in the fields of industrial hygiene, exposure assessment, toxicology, occupational and aerospace medicine, epidemiology, microbiology, aerospace and environmental engineering, air monitoring, ventilation and airflow modeling, and environmental chemistry. (App. II lists the members of the committee.) The committee examined the existing literature on this issue and made recommendations for potential approaches for improving cabin air quality. We also independently reviewed other studies on issues related to cabin air quality, paying particular attention to those issued after the publication of the National Research Council report.[5] We also gathered information from airlines and the governments of Australia, Canada, and the United Kingdom because of the research these countries have done on airliner cabin air quality. We also interviewed officials representing the World Health Organization (WHO), the Centers for Disease Control and Prevention (CDC), the Federal Aviation Administration (FAA), the National Institute for Occupational Safety and Health (NIOSH), the Aerospace Medical Association (AsMA), the Air Transport Association (ATA), the Association of Flight Attendants (AFA), the International Airline Passengers Association (IAPA), and aircraft and air filter manufacturers. We also interviewed several recognized experts on cabin air quality issues. In

[5]See the Selected Bibliography at the end of this report and, in particular, Hocking, Martin B., "Trends in Cabin Air Quality on Commercial Aircraft: Industry and Passenger Perspectives," *Reviews on Environmental Health* 17, 1 (2002): 1-49; and Rayman, Russell B., "Cabin Air Quality," *Aviation, Space and Environmental Medicine* 73 (2002): 211-215.

addition, we interviewed 11 of the 13 members[6] of the National Research Council Committee on Air Quality in Passenger Cabins of Commercial Aircraft that produced the 2001 report to obtain their views on the status of the report's recommendations and other cabin air quality issues, including leveraging expertise outside of FAA, such as the Environmental Protection Agency for its large body of research on indoor air quality and NIOSH for its role in conducting public health and air quality research. Finally, we contacted the 14 largest U.S. airlines that use Airbus, Boeing, or McDonnell Douglas aircraft to determine the extent to which their aircraft fleets use high-efficiency particulate air (HEPA) filters[7] on recirculated cabin air. Twelve of these 14 airlines responded, allowing us to determine HEPA filter usage rates for approximately 90 percent of the aircraft in our study population. We also obtained information from an aviation publication and the manufacturers of regional jets (typically aircraft that seat 100 or fewer passengers) on the extent of HEPA filter usage in these aircraft. We conducted our work from April 2003 through December 2003 in accordance with generally accepted government auditing standards. See appendix I for additional information on our objectives, scope, and methodology.

Results in Brief

Despite a number of studies of the air contaminants that passengers and flight attendants are potentially exposed to in airliner cabins and complaints by cabin occupants about health effects from poor cabin air quality, little is known about the extent of associated health effects. Reports published by the National Research Council in 1986 and 2001 on what was then known about airliner cabin air quality concluded that more research was needed to determine the nature and extent of health effects on passengers and cabin crew and that available air quality data are not adequate to address critical questions on aircraft cabin air quality and its possible effects on cabin occupant health. While aircraft manufacturers

[6]The NRC committee consisted of 13 members. We attempted to contact all 13 members. We interviewed 11, and 8 members responded to cabin air quality questions and the implementation status of their recommendations. Of the 11 committee members interviewed, 3 declined to address our questions, stating that they did not follow the progress of FAA's implementation of the recommendations. For example, 1 member stated that as a toxicologist, he could not comment on the overall approach FAA is taking to address the NRC recommendations.

[7]For purposes of this report, we use the Environmental Protection Agency's definition of HEPA, which is a filtering efficiency of 99.97 percent.

have made significant improvements to aircraft ventilation systems, passengers and cabin crews are still exposed to a number of air contaminants, such as allergens and infectious agents. Passengers and crew are also subjected to airflow rates that are lower than those recommended for buildings and to air pressures and humidity levels that are lower than those normally present at or near sea level. This exposure can pose a health risk to passengers with certain medical conditions, such as lung, heart, and circulatory disorders. In addition, poor cabin air quality has been associated with such discomforts as eye and nasal passage irritation.

The 2001 National Research Council report on airliner cabin air quality made 10 recommendations directed largely to the Federal Aviation Administration (FAA) to collect more information on the potential health effects of cabin air quality and to review the adequacy of its standards for air quality in commercial airliner cabins. To varying degrees, the agency has addressed the recommendations for which it is responsible. FAA is attempting to balance the need for additional research on the potential health effects of cabin air quality with other research priorities, such as improving passenger safety. However, some in the aviation community, including members of the Council committee who prepared the report, do not feel that FAA's planned actions will adequately address all of its recommendations on cabin air quality. For example, several of the Council committee members were particularly concerned about FAA's approach to implementing the committee's principal recommendations that more comprehensive research on the health effects of cabin air quality is needed. In response to the committee's recommendations in this area, FAA is leading the development of a surveillance and research program intended to relate perceptions of discomfort or health-related symptoms of flight attendants and passengers to possible causal factors, such as air contaminants, reduced air pressures and airflows, jet lag, low humidity, or inactivity. However, FAA has not yet developed a detailed plan with key milestones and funding estimates for conducting the planned surveillance and research program. In addition, of the 8 committee members who discussed the recommendations with us,[8] all said that FAA's program was much more limited than the Committee had envisioned. For example, 2 of the 8 said that FAA's program does not include an adequate number and cross-section of aircraft types and flights for accomplishing its objective.

[8]Of the 11 members interviewed, 8 agreed to address our questions concerning the committee recommendations (see app. I).

One committee member was also concerned that the program is too heavily tied to the aircraft industry to ensure objectivity and independence. In addition, another committee member believes that although FAA has a committee to oversee the selection of the contractor for the program, it has not assembled an advisory committee to review the research design and monitor the implementation of the program. In addition, 3 committee members are concerned that the research effort may not be adequately funded. Furthermore, 6 of the committee members felt that FAA's approach for addressing its recommendation that increased efforts be made to provide cabin crew, passengers, and health professionals with information on health issues related to flying by creating links on the FAA Web site to relevant information from health organizations was inadequate because the links are difficult to navigate and need to be supplemented with other information dissemination methods, such as providing physicians with brochures to share with patients who are planning air travel.

Several technologies are available today that could improve cabin air quality (e.g., by filtering or removing contaminants, increasing cabin humidity and raising cabin pressure, or absorbing more cabin odors and gasses), but opinions vary on whether FAA should require aircraft manufacturers and airlines to use these technologies. Aircraft manufacturers contend that unless future research proves otherwise, the ventilation systems in the aircraft that they have produced provide ample amounts of relatively clean air. Most aircraft currently in production have ventilation systems that recirculate cabin air. In addition, all of the new large commercial airliners in production that carry more than 100 passengers and have ventilation systems that recirculate cabin air come equipped with high-efficiency particulate air (HEPA) filters, which are highly effective (99.97 percent) at capturing airborne contaminants, such as viruses, when properly fitted and maintained. According to our survey of major U.S. air carriers, 85 percent of commercial airliners in the current U.S. fleet that recirculate cabin air and carry more than 100 passengers use HEPA filters. However, we found that only a small portion of the smaller regional jets that recirculate cabin air are using these filters. According to the manufacturers, most of these aircraft have no provision for installing any type of filter for their recycled air and could not be retrofitted with HEPA filters without extensive modifications. Nevertheless, given the proven effectiveness of HEPA filters, some National Research Council committee members and health officials believe that FAA should require them on all aircraft with recirculation systems. GAO also found that HEPA filters are relatively low cost when their use does not require modifying the existing ventilation system. In addition, airflow rates could be increased in some aircraft by adjusting settings on the ventilation system to reduce the effects of some airborne contaminants by diluting their concentration. However, this would be done at the expense of higher fuel consumption, increased engine emissions, and lower cabin humidity. Finally, both Boeing and Airbus—the world's two largest airframe manufacturers—are considering using air quality improvement technologies (e.g., increasing cabin humidity) to improve passenger comfort on the long-range commercial aircraft that they are developing.

To help ensure that FAA's research and surveillance efforts on airliner cabin air quality answer critical outstanding questions about the nature and extent of potential health effects of cabin air quality on passengers and flight attendants, GAO recommends that the FAA Administrator (1) develop a detailed plan for the research and surveillance efforts, including key milestones and funding estimates; (2) appoint a committee of acknowledged experts in the fields of aircraft ventilation and public health, including representatives of EPA and NIOSH, to assist in planning and overseeing the research and surveillance efforts; (3) leverage the findings of international counterparts' research on airliner cabin air quality to inform FAA's surveillance and research efforts; and (4) report to Congress annually on the progress and findings of the research and surveillance efforts and funding needs.

In addition, to help improve the healthfulness of cabin air for passengers and cabin crews, GAO also recommends that the FAA Administrator assess the costs and benefits of requiring the use of HEPA filters on commercial aircraft with ventilation systems that recirculate cabin air. GAO also recommends that FAA should go farther in addressing the Council recommendation to increase efforts to provide the public with information on the health risks of flying by taking additional steps to improve its methods for disseminating this information, such as improving the ease with which the public can access this information on FAA's Web site and systematically disseminating such information to physicians and their patients through various medical associations.

Background

Since people began traveling in pressurized, climate-controlled aircraft more than 40 years ago, questions have arisen about the quality of air inside aircraft cabins and its effect on the health of passengers and cabin crews. In addition, the number of people traveling by commercial aircraft has increased dramatically over the years, with more than 600 million passengers flown by U.S. carriers in 2002 alone. Despite a downturn in air travel following the events of September 11, 2001, FAA expects demand to recover and then continue a long-term trend of 3.6 percent annual growth. As air travel has become more accessible, the flying public mirrors the general population more closely than in years past. Therefore, it includes more young and elderly passengers who can be more susceptible to potential health risks associated with air travel. This diverse group of passengers, as well as the cabin crew, experiences an environment in the aircraft cabin that in some ways is similar to that of homes and buildings but in other ways is distinctly different. The National Research Council (the Council)—the principal operating agency of the National Academy of Sciences—has issued two reports at the request of Congress on the air quality in aircraft cabins, one in 1986 and another in 2001.[9] The 2001 Council report notes that the aircraft cabin is a unique environment in which the occupants are densely confined in a pressurized space. The report goes on to note that airline passengers encounter environmental factors that include low humidity, reduced air pressure, and potential exposure to air contaminants, including ozone, carbon monoxide, pesticides, various organic chemicals, and biological agents that can have serious health effects. The report concluded that there are still many unanswered questions about how these factors affect cabin occupants' health and comfort and about the frequency and severity of incidents in which heated oils or hydraulic fluids release contaminants into the cabin ventilation system. Figure 1 shows the passenger cabin of a commercial aircraft.

[9]National Research Council, *The Airliner Cabin Environment: Air Quality and Safety*, National Academy Press (Washington, D.C.: 1986) and National Research Council, *The Airliner Cabin Environment and the Health of Passengers and Crew*, National Academy Press (Washington, D.C.: Distributed electronically December 2001; bound report copyrighted 2002).

Figure 1: Passenger Cabin of Commercial Airliner

Source: Markus Wechselberger.

As depicted in figure 2, supplying air to modern jet airliner cabins is a complex process that varies somewhat among airplane models but has essential characteristics that are shared by most airliners. Basically, some of the outside air that enters the aircraft engines is diverted and processed for use in the cabin in order to achieve an air pressure and temperature closer to that experienced on the earth's surface. FAA requires that air supplied to aircraft be designed to maintain a cabin pressure equivalent to that at an elevation of no more than 8,000 feet, which is similar to the elevation of Mexico City (7,500 ft.). Nevertheless, the air pressures inside aircraft cabins are much higher than the extremely low outside air pressures at normal cruising altitudes of 25,000 to 40,000 feet. After flowing through the engines, the air enters an intricate system of cooling devices and ducts and is distributed throughout the cabin and cockpit.

Airlines that fly in areas where ozone levels are high[10] are required to take steps to ensure that ozone levels do not exceed prescribed standards (e.g., by having a device that converts the ozone pollutant into oxygen before it enters the cabin and cockpit). The Council reported that unacceptable high ozone levels can occur in passenger cabins of commercial aircraft in the absence of effective controls. On most modern aircraft, an average of about 56 percent of the outside air supplied to the cabin is vented out of the aircraft through valves that help regulate cabin pressure. The remaining air is then recirculated through the cabin; this recirculation allows the engines to use less fuel for air supply and pressurization. In addition to less fuel and pressurization, recirculation also provides the benefit of higher airplane cabin humidity, improved airflow patterns, and minimized temperature gradients. On most large aircraft, the recirculated air typically passes through filters that are designed to remove harmful particulates, such as viruses and bacteria.[11] FAA requires that aircraft ventilation systems for aircraft designs certified after June 1996 be designed to supply at least 10 cubic feet per minute of outside air per person under standard operating conditions. This compares with the standard minimum rate of 15 cubic feet per minute per person for buildings recommended by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).[12] However, according to FAA officials, there is currently no standard for cabin ventilation rate, and it has yet to be determined if it is appropriate to compare building and aircraft ventilation rates because outside air at altitude is very clean, while air sources for buildings are often contaminated by pollution. Furthermore, in rare instances, oil leaks or other engine malfunctions can cause contaminants such as carbon monoxide to be released into the cabin ventilation system. The 2001 Council report noted that questions about the frequency and significance of such incidents remain unanswered. In February 2002, FAA published a report that discussed many of the issues in the Council report, including an

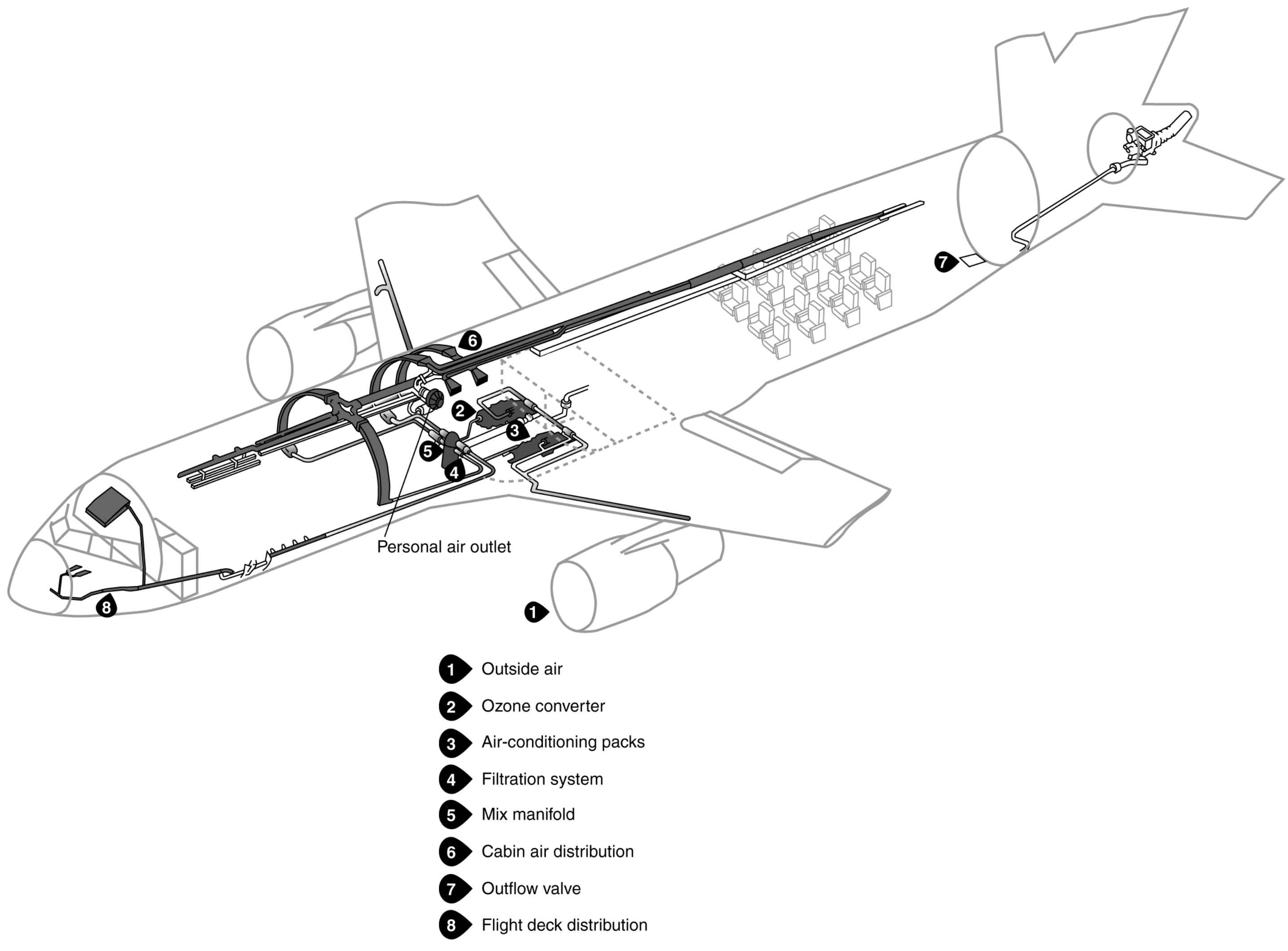
[10]The 2001 Council study reported that the effects of ozone vary with latitude, altitude, and season and that the concentration of ozone is much higher at cruise altitudes in high latitudes (greater than approximately 60°N) than at low latitudes (approximately 30°N), resulting in higher concentrations of ozone on polar flights.

[11]FAA does not require these filters; however, our survey of U.S. airlines found that 85 percent of the large aircraft (those that carry 100 passengers or more) currently use HEPA filters.

[12]The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) advances the arts and sciences of heating, ventilation, air conditioning, refrigeration, and related human factors to serve the evolving needs of the public.

estimate of 416 air contaminant events (or 2.2 events every 1,000,000 aircraft hours) that may have taken place in commercial transports within the United States between January 1978 and December 1999.

Figure 2: Overview of How Air Is Supplied on a Commercial Airliner



Source: Reproduced with permission from the Boeing Company.

(1) Outside air continuously enters the engine, where it is compressed.

(2) It then passes through a catalytic ozone converter (in some aircraft) to air-conditioning packs.

(3) The air passes through cooling packs to a mixing manifold.

(4) Outside air entering the mixing manifold is mixed with recirculated air that has been cleaned with high-efficiency filters.

(5) The makeup of air in the mixing manifold is approximately 50 percent outside and 50 percent filtered, recirculated air.

(6) Air from the mixing manifold is then supplied to the cabin on a continuous basis from overhead outlets.

(7) As outside air enters the airplane, air is continuously exhausted from the airplane.

(8) Mixed outside and filtered recirculated air is provided to the flight deck from the mixing manifold.

FAA is responsible for setting design standards for aircraft ventilation systems. To fulfill its responsibilities, FAA requires that manufacturers design and build their large commercial airplanes to meet specific engineering standards, which limit the amounts of certain air quality contaminants (e.g., carbon monoxide, carbon dioxide, and ozone) that can be present in an airliner cabin. Manufacturers comply with these engineering standards in order to have FAA certify their airplanes as airworthy.[13] However, while FAA monitors overall aircraft system operations, it does not require airlines to monitor cabin air quality during their operations to determine if air quality during routine flight operations is meeting the agency's engineering standards. According to FAA, the certification requirements combined with the monitoring of overall aircraft system operations are sufficient. However, the 2001 Council report stated that because of a lack of data it was not able to answer questions about the extent to which aircraft ventilation systems are operated properly.

Despite a Number of Studies, Data Are Lacking About the Effects of Air Quality On Cabin Occupants

Passengers and flight attendants have had long-standing concerns about negative health effects from the quality of air in airliner cabins; however, research to date, including two reports by the Council, has not been able to definitively link the broad, nonspecific health complaints of passengers and flight attendants to possible causes, including cabin air quality. In its most recent report, the Council concluded that critical questions about the potential effect of cabin air quality on the health of cabin occupants remain

[13]According to FAA officials, FAA regulations have always required limitations on certain contaminants (e.g., carbon monoxide and carbon dioxide). Later amendments added ozone and changed the ventilation requirements. However, these officials stressed that airplanes are certified to the regulations in effect at a certain time prior to their manufacture. Only the latest certified airplanes will have had to meet the latest amendment level for the regulations governing the cabin environment, such as a 1996 amendment which added the requirement that each occupant be provided with 0.55 pounds (equivalent to 10 cubic feet) of fresh air per minute under standard operating conditions.

unanswered because existing data are inadequate, and it recommended further research to narrow this knowledge gap.

Passengers and flight attendants (cabin occupants) have long complained of acute and chronic health effects during and after flying. Many complaints made by cabin occupants are relatively minor, such as dry eyes and nose, or the onset of colds soon after flying, but others are much more serious. According to the Association of Flight Attendants, its members have reported such health problems as respiratory diseases, nausea, dizziness, muscle tremors, nervous system damage, and memory loss.[14] The association notes that these illnesses are consistent with exposure to carbon monoxide, pesticides, reduced oxygen levels, neurotoxins, and ozone gas, all of which can be present in the cabin itself or in cabin air supplies, depending on the flight. In addition, passengers with certain medical conditions can be at higher risk from the quality of cabin air than the general population due to air contaminants, lowered oxygen levels in the body (hypoxia), and changes in cabin pressure. Such medical conditions include limited lung capacity (e.g., asthma) and cardiovascular and circulatory disorders. Those who fly soon after surgery are particularly vulnerable to changes in cabin pressure. However, according to the Council report, many of the complaints made by cabin occupants are so broad and nonspecific that they could have many causes, and it is difficult to determine a specific illness or syndrome.

Although numerous studies have been conducted on cabin air quality issues, there are insufficient data to determine the nature and extent of cabin air quality's effect on cabin occupants. Council reports published in 1986 and 2001 reviewed the literature on cabin air quality issues and concluded that the studies had not collected data in a systematic manner that would conclusively address many of the questions about potential exposures in aircraft cabins and their health effects. Both reports recommended actions for improving what is known about cabin air quality, including the need to collect better data on the potential effect of cabin air quality on passenger and cabin crew health. The 2001 report concluded that available data on air quality and its possible negative effects on cabin

[14]ATA officials noted that these symptoms are also consistent with a host of other causes, such as lack of sleep (perhaps due to difficulty in adjusting to different time zones), dehydration (possibly from drinking too much caffeine or alcohol and not enough water during a long flight), the effect of changes in climate, or exposure to contaminants in other settings.

occupant health have left three critical outstanding questions unaddressed and that additional research is needed:

- Do current aircraft as operated comply with FAA design and operational limits for ventilation rate and for chemical contaminants, including ozone, carbon monoxide, and carbon dioxide, and are the existing air quality regulations adequate to protect health and ensure the comfort of passengers and cabin crew?

- What is the association, if any, between exposure to cabin air contaminants and reports or observations of adverse health effects in cabin crew and passengers?

- What are the frequency and severity of incidents when air contaminants enter the cabin due to nonroutine conditions such as oil leaks or other engine malfunctions?

Following the 1986 report, the Department of Transportation sponsored a study to evaluate the health risks posed by exposures to contaminants on randomly selected flights. In addition, various researchers conducted a number of studies of cabin air quality issues, including eight investigations of biological agents, such as viruses and bacteria, on commercial aircraft. However, these and other studies were not able to link the broad, nonspecific health complaints that passengers and cabin crew continued to make to possible causes, including cabin air quality.

Recognizing the need for more data on the issue, Congress directed FAA, in AIR-21,[15] to request that the Council perform another independent examination of cabin air quality. The Council's report, issued in 2001, concluded that when operated properly, the environmental control system[16] should provide an ample supply of air to pressurize the cabin, meet general comfort conditions, and dilute or reduce normally occurring odors, heat, and contaminants. However, the Council also found

[15]The Wendell H. Ford Aviation Investment and Reform Act for the 21st Century (AIR-21), Public Law 106-181, April 5, 2000.

[16]The environmental control system includes devices that pressurize the cabin in flight, control thermal conditions in the cabin, and ventilate the cabin with outside air to prevent a buildup of contaminants that might cause discomfort or present a health hazard.

that the design standard for ventilation rates[17] in aircraft required by FAA was less than one-half to two-thirds the rate recommended by ASHRAE for buildings. The Council noted that whether the building ventilation standard is appropriate for the aircraft cabin environment has not been established.[18] Studies have shown that low ventilation rates in buildings have contributed to "sick building syndrome," which causes fatigue, headache, and throat irritation. However, FAA officials told us that a sick building syndrome comparison is not applicable, in part because HEPA filtration results in much cleaner recirculated air than in a building environment.

The 2001 Council report also found that although the environmental control system in aircraft is designed to provide adequate air pressure and minimize the concentration of contaminants in the cabin, passengers and cabin crew are potentially exposed to air quality-related health risks. The Council was particularly concerned about two cabin air characteristics and suggested that they be given high priority for further investigation. The first is reduced oxygen partial pressure, which results from the lower air pressures present in aircraft cabins at cruise altitudes. Most healthy individuals are unaffected by reduced oxygen partial pressure, but those with health problems such as cardiopulmonary disease and infants can experience serious health effects from a lack of oxygen (e.g., respiratory stress). The other concern of the Council was elevated concentrations of ozone, which can occur at high cruise altitudes over certain areas of earth, such as the Arctic. The Council reported that unacceptably high ozone levels could occur in passenger cabins of commercial aircraft in the absence of effective controls. FAA allows aircraft operators to maintain cabin ozone concentrations at or below prescribed limits through flight planning that avoids areas with ozone concentrations exceeding those limits or the installation of devices that convert ozone to oxygen. However, FAA does not have a process in place to ensure that ozone converters are

[17]The ventilation rate is the flow of outside air supplied to the cabin for ventilation and it does not normally include recirculated air even though recirculated air may be used for cabin ventilation.

[18]According to FAA officials, a comparison of ventilation rates for buildings and aircraft is not valid and that "sick building syndrome" should not be applied to aircraft. Furthermore, both FAA and Boeing officials told us that the new ASHRAE standards for buildings create two sets of building standards for ventilation—one for high density buildings and another for low density buildings. Boeing officials said that under this standard, high density buildings would have lower airflow rates per occupant, and that high density buildings are most comparable to airplanes with high density occupancy.

installed in all aircraft that fly routes where ozone may pose a risk or that converters in service are operating properly.

The Council also had what it termed moderate concern about several other potential air quality-related exposures on aircraft, but it noted that there were little data available on the frequency at which they occur. For example, according to the Council, infectious agents, such as viruses and bacteria, were likely present on aircraft, and high occupant densities could increase the risk of transmittal. The Council observed, however, that air recirculation did not increase the risk of transmittal, especially in systems using HEPA filters. Likewise, the Council noted that airborne allergens, such as cat dander, could pose problems for passengers with sensitivities. In addition, when aircraft are on the ground, according to the Council, passengers can be exposed to contaminants from engine exhaust, such as carbon monoxide and other outdoor air pollutants, including ozone and particulate matter, when they are pulled into the aircraft through the ventilation system. Also of some concern to the Council were incidents when lubricating and hydraulic fluids seep into the aircraft ventilation system during engine and other system malfunctions. Although such occurrences are rare, and the actual exposure to contaminants resulting from them is unknown, lubricating and hydraulic fluids contain substances that can pose neurological health risks to passengers and cabin crew if they are present in sufficient concentrations and for a sufficient length of time. Finally, the Council was somewhat concerned about exposures to the pesticide spraying that takes place on some international flights,[19] which can cause skin rashes and other health effects. Table 1 summarizes information presented by the Council on the potential air quality-related exposures on aircraft.

[19]Disinsection is the process of spraying the aircraft cabin with insecticide to prevent the conduction of insects such as mosquitoes from one country to another. The spraying is often done while passengers and crewmembers are still on board. The United States terminated this practice in 1979 because of health concerns and doubts about the effectiveness of the spraying. Over the years, a number of countries have changed their policies regarding the spraying of pesticides. The Department of Transportation is studying alternative technological methodologies, including air curtains to prevent airborne insects from flying into the aircraft cabin.

Table 1: Potential Air Quality Related Concerns on Aircraft Cited by the National Research Council in 2001

Characteristic	Potential health impacts	Exposure frequency	Availability of information
High concern			
Cabin pressure	Serious health effects may occur in infants and those with cardio-respiratory diseases from lack of oxygen. Temporary discomfort or pain from gas expansion in middle ears or sinuses.	Reduced cabin pressure occurs on nearly all flights.	Reliable measurements are available; health effects in some sensitive groups are uncertain.
Ozone	Airway irritation and reduced lung function.	Elevated concentrations are expected primarily on aircraft without ozone converters.	Few systematic measurements made since 1986 Council report.
Moderate concern			
Airborne allergens	Irritated eyes and nose, sinusitis, acute increases of asthma, or anaphylaxis.	Not known.	Only self-reported data are available.
Carbon monoxide	Headaches and lightheadedness occur at low concentrations, more serious health effects result from higher concentrations.	High concentrations could occur during air-quality incidents. Frequency of incidents is highly uncertain but is believed to be low.	Reliable measurements are available for normal operating conditions, but no data are available for incidents.
Hydraulic fluids	Mild to severe health effects can result from exposure to these fluids.	Frequency of incidents in which these fluids enter the cabin is uncertain but is expected to be relatively low.	No quantitative data are available. Little information is available on health effects related to smoke, mists, or odors in aircraft cabins.
Pesticides	Skin rashes can result from skin or inhalation exposure.	Exposure likely on some international flights.	Only self-reported data are available.
Low concern			
Carbon dioxide	Indicator of ventilation adequacy. Elevated concentrations associated with increased perceptions of poor air quality.	Concentrations are generally below FAA regulatory limits.	Reliable measurements are available only for normal operating conditions.
Nuisance odors	Annoyance and mucous membrane 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 relative low humidity (10 to 20%).	Relative low humidity occurs on most flights.	Reliable and accurate measurements in aircraft are available.

Source: National Research Council.

Since the issuance of the 2001 Council report, some limited studies have examined specific air quality issues, such as infectious disease transmission, but they have raised as many questions as they have answered. For example, according to a revised 2003 WHO report on tuberculosis (TB) and air travel, as of August 2003, no case of active TB has been identified as resulting from exposure while on a commercial aircraft.[20] The report did note, however, that there is some evidence that transmission of TB may occur during long flights (i.e., more than 8 hours) from an infectious source (passenger or crew) to other passengers or crewmembers. In 2002, the American Medical Association[21] did not find any evidence that aircraft cabin air recirculation increases the risk for upper respiratory tract infection (URI) symptoms in passengers traveling aboard commercial jets. However, passengers had higher incidents of URI infections than the general public within a week after completing their trips. One of the study's authors noted that the research indicated that while flying increases the risk of getting colds or other infections, an aircraft's ventilation system may not be a key factor. A 2003 study appearing in the New England Journal of Medicine found that SARS transmissions may occur on flights carrying people in the symptomatic stages of the disease. (See app. II for more details on this study.[22])

FAA has Taken Action to Address Council Recommendations On Cabin Air Quality, but These Efforts Could Be Improved

The December 2001 Council report on airliner cabin air quality made 10 recommendations about air quality standards for the cabins of commercial airliners and the need for more information concerning the health effects of cabin air. Nine of these recommendations were directed to FAA, and it has implemented them to varying degrees. The Council report's 10 recommendations focused on five aspects of cabin air quality and its environment: (1) the establishment of cabin air quality surveillance and research programs, (2) FAA's oversight of the operation of aircraft ventilation systems, (3) exposures on aircraft due to the transport of small animals in aircraft cabins, (4) distribution of health related information, and (5) recommended procedures as a result of a ventilation system shutdown. Although one recommendation asked Congress to designate a lead federal agency for conducting airliner cabin air quality research, most of the recommendations were directed at or involved FAA. Table 2 describes each of the Council report recommendations and FAA's response.

[20] World Health Organization, *Tuberculosis and Air Travel: Guidelines for Prevention and Control* (Geneva, Switzerland: Aug. 27, 2003).

[21] Zitter, Jessica, Peter Mazonson, Dave Miller, Stephen Hulley, and John Balmes, "Aircraft Cabin Air Recirculation and Symptoms of the Common Cold," *Journal of the American Medical Association* 288 (2002): 483-486.

[22] Olsen, Sonja J. et al., "Transmission of the Severe Acute Respiratory Syndrome on Aircraft," *The New England Journal of Medicine* 349; 25 (2003): 2416-2422.

Table 2: Status of the National Research Council's 2001 Report Recommendations on Airliner Cabin Air Quality

Council Report Recommendations	FAA's Response
Cabin Air Quality Surveillance and Research Programs	
Surveillance program 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 appendix V of this report. 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.	FAA is addressing this recommendation through a joint research effort combining the resources of FAA and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).
Research program To answer specific questions about cabin air quality, a research program should be established. See appendix V of this report for a summary of research questions, objectives, and research program approach.	FAA is addressing this recommendation through a joint research effort combining the resources of FAA and ASHRAE.
Research program lead agency The Council committee recommends that Congress designate a lead federal agency and provide sufficient funds to conduct or direct the research program recommendation (see above), 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.	Congress has designated FAA as the lead agency to direct the cabin air quality research program, but, according to FAA officials, has not appropriated sufficient funds to support it.
FAA Oversight of Aircraft Ventilation Systems	
Air quality regulations FAA should rigorously demonstrate in public reports the adequacy of current and proposed Federal Aviation Regulations (FARs) related to cabin air quality and should provide quantitative evidence and rationales to support sections of the regulations that establish air quality-related design and operational standards for aircraft (standards for carbon monoxide, carbon dioxide, ozone, 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.	Necessary data to implement this recommendation will be available upon completion of the ASHRAE study in late 2006 or early 2007.
Regulations for ozone FAA should take effective measures to ensure that the current FAR for ozone (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 ozone converters be installed, used, and maintained on all aircraft 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 ozone concentrations are not exceeded in reasonable worst-case scenarios. To ensure compliance with the ozone requirements, FAA should conduct monitoring to verify that the ozone controls are operating properly (see also surveillance program recommendation).	Necessary data to implement this recommendation will be available upon completion of the ASHRAE study.

(Continued From Previous Page)

Council Report Recommendations	FAA's Response
Air cleaning equipment 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 environmental control system (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.	Necessary data to implement this recommendation will be available upon completion of the ASHRAE study.
Carbon monoxide monitoring FAA should require a carbon monoxide monitor in the air supply ducts to passenger cabins and establish standard operating procedures for responding to elevated carbon monoxide concentrations.	Necessary data to implement this recommendation will be available upon completion of the ASHRAE study.
Exposures on Aircraft, Health Information, and Ventilation Shutdown Procedures	
Allergens 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.	FAA issued an advisory circular providing guidance regarding air carrier passenger handling procedures for allergen-sensitive people, but did not prohibit the transport of animals on aircraft, particularly service animals. Agency officials do not think that a prohibition on animals in the cabin would be effective in minimizing animal allergens because they believe that these allergens are brought on board aircraft primarily on the clothes of passengers.
Health information 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.	The FAA's Office of Aerospace Medicine made health information and recommendations available to passengers and crews through its Web site and linked the site to other health-related organizations. The agency also developed a brochure on the potential risk of developing a condition known as deep vein thrombosis (DVT), in which blood clots can develop deep in the veins of the legs after extended periods of inactivity. This brochure has been distributed to aviation medical examiners and cited in the Federal Air Surgeon's Bulletin.
Ventilation shutdown The committee reiterates the recommendation of the 1986 Council 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 ensure the maintenance of full ventilation whenever on-board or ground-based air conditioning is available.	FAA concurred with the objective of the recommendation and advised air carriers, through advisory circulars, to deplane passengers as long as operational safety is not compromised.

Sources: National Research Council and GAO analysis of FAA documents.

Note: Federal Aviation Regulations are legal requirements and rules for the aviation industry set by the Federal Aviation Administration.

FAA formed the Airliner Cabin Environment Report Response Team to review the findings of the NRC report on airliner cabin air quality and published a planned response in February 2002. However, many of the actions included in this plan were contingent on the formation of an aviation rulemaking advisory committee, on which the agency has deferred action. FAA subsequently updated its plans, as reflected above.

We reviewed FAA's approach for addressing the recommendations and found that the agency has made progress on implementing some of them, including those relating to making information available on potential health issues related to cabin air quality and the risks posed to sensitive people by allergens from small animals transported in aircraft cabins; however action on others is pending. For example, recommendations to improve FAA oversight of aircraft ventilation systems are pending until completion of the ASHRAE study in late 2006 or early 2007. In implementing the Council report recommendations, FAA is attempting to balance the need to conduct additional research on the healthfulness of cabin air quality with other research priorities, such as improving passenger safety. Our prior work on airliner cabin safety and health has underscored the importance of setting risk-based research priorities, in part by establishing cost and effectiveness estimates to allow direct comparisons among competing research priorities. In commenting on this prior work, FAA cautioned that if too much emphasis is placed on cost/benefit analyses, potentially valuable research may not be undertaken.[23] We concur in that caution. Similarly, we found that many members of the Council committee on airliner cabin air quality question FAA's approach to implementing some of the recommendations it made, particularly those related to the committee's principal finding that more comprehensive research on the health effects of cabin air quality is needed. Specifically, some in the aviation community have raised concerns that FAA's planned actions for implementing the Council recommendations on cabin air quality, including its research and surveillance efforts, will not be adequate to answer long-standing questions about the nature and extent of potential health effects posed by cabin air.

Council Recommendations Calling for Cabin Air Quality Surveillance and Research Programs

To address the need for more information on the health effects of cabin air quality, the 2001 Council report made three recommendations regarding the establishment of cabin air quality surveillance and research programs. FAA, in coordination with ASHRAE, has begun to develop a program to monitor air quality on some flights and correlate this information with

[23] U.S. General Accounting Office, *Aviation Safety: Advancements Being Pursued to Improve Airliner Cabin Safety and Health*, GAO-04-33 (Washington, D.C.: October 3, 2003).

health data collected from passengers and cabin crews. Although this effort can provide a foundation for future research, members of the committee that produced the report are concerned that its scope is too limited to adequately answer long-standing questions concerning the association between cabin air quality and health effects.

Council Concluded That Surveillance and Research Programs Needed to Answer Outstanding Questions Concerning Cabin Air Quality

According to a committee member, the Council report's most important recommendations are those pertaining to the establishment of cabin air quality surveillance and research programs. The report concluded that available air quality data are not adequate to address three critical questions on aircraft cabin air quality and its possible effects on cabin occupant health:

- Do current aircraft, as operated, comply with FAA design and operational limits for ventilation rate and for chemical contaminants, including ozone, carbon monoxide, and carbon dioxide, and are the existing air quality regulations adequate to protect the health and ensure the comfort of passengers and the cabin crew?
- What is the association, if any, between exposure to cabin air contaminants and reports or observations of adverse health effects in cabin crew and passengers?
- What are the frequency and severity of incidents when air contaminants enter the cabin due to nonroutine conditions such as oil leaks or other engine malfunctions?

To answer these questions, the Council report recommended a dual approach that includes a routine surveillance program and a more focused research program. The report said that the surveillance program should continuously monitor and record chemical contaminants, cabin pressure, temperature, and relative humidity in a representative number of flights over a period of 1 to 2 years. Thereafter, the program should continue to monitor flights to ensure accurate characterization of air quality as existing aircraft equipment ages or is upgraded. In addition to air quality monitoring, the report said the surveillance program should also include the systematic collection, analysis, and reporting of health data, with the cabin crew as the primary study group. The report said a detailed research program to investigate specific questions about the possible association between air contaminants and reported health effects should supplement the surveillance program. Among the subjects suggested for research are the factors that affect ozone concentration in cabin air and the adequacy of outside air ventilation flow rates.

FAA Has Taken the Lead in Developing Surveillance and Research Programs

In order to implement the surveillance and research programs, the report recommended that Congress designate a lead federal agency and provide sufficient funding to conduct or direct the research program to fill the major knowledge gaps. It also called for an independent advisory committee with appropriate scientific, medical, and engineering expertise to oversee the programs to ensure that the research program's objectives are met. In response, as a part of FAA's reauthorization, Congress designated FAA as the lead federal agency.[24] Prior to this, FAA acted in this capacity and allocated limited funding for this effort, although, according to FAA officials, Congress provided no additional funding through fiscal year 2003 for air quality surveillance and research; however, pending legislation for fiscal year 2004 would provide $2.5 million for this effort. In addition, on March 4, 2003, FAA announced the creation of a voluntary program for air carriers, called the Aviation Safety and Health Partnership Program. Through this program, the agency intends to enter into partnership agreements with participating air carriers, which will, at a minimum, make data on their employees' injuries and illnesses available to FAA for collection and analysis. According to FAA officials, this program has a reporting system and database available to capture air quality incidents.

In taking the lead for implementing the recommendations for surveillance and research programs, FAA has undertaken a joint effort with ASHRAE. According to FAA, this joint effort will build on a previous study conducted for FAA by NIOSH, which identified and characterized potential health issues, including respiratory effects, related to the aircraft cabin

[24]Vision 100—Century of Aviation Reauthorization Act," passed by Congress in November 2003, requires that FAA, at a minimum: 1) conduct surveillance to monitor ozone in the cabin on a representative number of flights and aircraft to determine compliance with existing regulations for ozone, 2) collect pesticide exposure data to determine exposures of passengers and crew, 3) analyze samples of residue from aircraft ventilation ducts and filters after air quality incidents to identify potential exposure of contaminants to passengers and crew, 4) analyze cabin air pressure and altitude, and 5) establish an air quality incident reporting system. The FAA administrator is to report the findings to Congress no later than 30 months after the date of the act's enactment.

environment, but did not link the health issues to cabin conditions.[25] The joint effort includes a surveillance and research initiative whose principal aim is to relate perceptions of discomfort or health-related symptoms that flight attendants and passengers have had to possible causal factors, including cabin and outside air quality and other factors, such as reduced air pressure, jet lag, inactivity, humidity, flight attendant duty schedule and fatigue, disruptions to circadian rhythm,[26] stress, and noise. While FAA's fiscal year 2004 appropriation in the research and development budget includes $2.5 million for cabin air research—including identifying bacterial and pesticide contamination and monitoring air quality incidents—it is unclear which of the cabin air quality projects outlined in the FAA reauthorization bill will be funded.[27] Additionally, ASHRAE officials stated that the surveillance and research initiative would support ASHRAE's ongoing efforts to develop air quality standards for commercial aircraft.

According to FAA, the surveillance and research program is to be carried out in two parts; the first started in December 2003 and the second will start in December 2004 and end in late 2006 or early 2007. In part I, air quality data will be collected on four to six flights on a minimum of two different types of aircraft, and the data will then be compared with health information gathered from surveys of passengers and crew on the flights. According to FAA and ASHRAE, the protocol and procedures developed in part I of the study will be the basis for conducting on-ground and in-flight monitoring in part II of the initiative. In part II, air quality monitoring will be conducted on different models of commercial jet airplanes representing a large section of the world fleet and will include a minimum number of

[25]NIOSH conducted the study over 2 years on 33 commercial flights on 10 different types of airplanes owned by four air carriers. NIOSH initially surveyed female flight attendants on reproductive health, but the survey was later expanded to include respiratory effects. The study did not include direct linkage to measurement of cabin environment conditions. The survey respondents flew on a wide variety of aircraft in which the cabin environment was not sampled.

[26]Circadian rhythm is the body's internal resting or wakefulness schedule over the course of a day. Outside influences, such as jet lag, can disrupt the circadian rhythm temporarily.

[27]FAA's fiscal year 2004 facilities and equipment budget includes $8.5 million to develop and demonstrate a chemical/biological detection and mitigation capability and decontamination procedures for aircraft occupants and for returning the aircraft to service.

flights that has not yet been determined.[28] However, according to FAA officials, the level of funding that will be available for part II is uncertain. FAA and ASHRAE have assembled a committee which is responsible for selecting a contractor to conduct the monitoring and health surveillance in part I and overseeing the contractor's performance. The committee consists of aircraft, health, and air quality experts, including five members of the Council committee, as well as representatives from FAA, the Association of Professional Flight Attendants, and the Boeing Commercial Airplane Group. In September 2003, the committee chose a contractor for part I, and work began in December 2003. FAA and ASHRAE have not yet selected a contractor for part II, although the estimated completion date for the entire program is late 2006 or early 2007.

ASHRAE officials stated that to date FAA, Boeing, and two major U.S. airlines are supporting this effort. FAA has provided $50,000 of the estimated $250,000 it will cost to conduct air quality surveillance on two aircraft. Boeing is the major source for the balance of the funding for the surveillance program. FAA had previously reported that it was seeking a $500,000 contract with the Johns Hopkins University Applied Physics Laboratory (APL) to develop devices to monitor the aircraft cabin environment as part of the research and surveillance program. However, the contract was not finalized because APL determined that the project would cost significantly more than $500,000 and FAA reprogrammed the funds. FAA said that it has not yet funded part II, while ASHRAE officials noted that they are planning to solicit the part I contributors again for part II once part I is under way.

Despite FAA's efforts to date, we found that the agency has not developed a detailed plan for the research and surveillance program, including key milestones and funding estimates, in keeping with generally accepted practices for oversight and independence. In addition, the agency has not created an independent panel of experts in the areas of aircraft ventilation, air quality, and public health to help plan and oversee this effort. Furthermore, FAA's plans do not explicitly include leveraging the findings of international research on cabin air quality.

[28]The minimum number of flights to be included will depend on the recommendations of part I and on the availability of research funds and will be specified in the solicitation for part II to be released by ASHRAE in the future.

Committee Members Concerned about Scope, Independence, and Funding of FAA Surveillance and Research Program

Members of the committee that produced the 2001 Council report are concerned that the FAA/ASHRAE surveillance and research program, as designed, will fall short of answering the long-standing questions about the effect of cabin air quality on passenger and cabin crew health and comfort. We contacted the 13 members of the committee, and 8 agreed to comment on FAA's response to their recommendations on cabin air quality surveillance and research. We refer to these 8 individuals from here forward as commenting committee members. Although 5 of 8 commenting committee members said that the initiative should shed some light on cabin air quality's effects on health, all said that it was much more limited than the committee had envisioned. Two of the 8 commenting committee members thought that the air quality and health surveillance initiative should be a continuous undertaking in which air quality and health information is taken from a representative sample of commercial aircraft and flight routes. They also said that it appears the FAA and ASHRAE program will not include a broad enough cross-section of aircraft and flights to determine the full range of air quality problems and relate them to health effects. Two commenting committee members said that part I of the FAA and ASHRAE program will extensively monitor cabin air quality on two aircraft types; however, part I will not provide information that is generalizable to the U.S. commercial airliner fleet. According to Boeing officials involved in this study, part I research is designed to validate test equipment and study protocols and is not designed to be generalized to the airliner fleet. One committee member said that although more aircraft are to be included in part II, it is doubtful that enough information will be collected to adequately answer the key questions the agency's research and surveillance program was designed to address. According to Boeing officials, part II includes plans for information collection to address the key question of the agency surveillance and research program, provided sufficient funds are available. Another commenting committee member said that the FAA and ASHRAE program would also yield little or no information on air quality incidents that occur when cabin air is contaminated by oil or hydraulic fuel leaks. According to the member, these incidents are rare and can be monitored only if simple, inexpensive equipment (e.g., devices that can "grab" samples) is available to cabin crew on a large number of flights to use in the event that an incident occurs. FAA officials said that issues of sampling adequacy and specimen handling could complicate the grab sample approach. These officials also noted that a voluntary injury and illness reporting system that it has in place could capture air quality incidents if it were made mandatory.

Seven of the eight commenting committee members also noted that FAA has not adequately addressed the Council report's recommendations regarding cabin air surveillance and research programs. FAA has indicated that its program responds to the report's recommendations calling for surveillance and research efforts. However, these committee members believe that the program focuses only on surveillance and does not include in-depth research of air quality issues as outlined in the committee's recommendation calling for a separate comprehensive research program.

One of the commenting committee members said that a cabin air quality study currently under way in Europe contains many of the elements that the committee had hoped to see in the U.S. surveillance and research efforts. As part of the ongoing surveillance and research study, the European cabin air study[29] is currently coordinated by Building Research Establishment, Ltd. (BRE).[30] The study focuses on three major goals: (1) advancing the industry's understanding of what is known about air quality issues by assessing the current level of air quality found in aircraft cabins; (2) identifying the technology (i.e., environmental control systems including filtration and air distribution) that is available to improve cabin air quality; and (3) assessing and determining potential improvements to existing standards and performance specifications for the cabin environment. (The scope and methodology for Europe's cabin air study is found in appendix IV). The cabin air study partnered (to various degrees) with 16 organizations, including Boeing, Airbus Deutschland, Honeywell (manufacturer of environmental control systems), Pall Aerospace (filter manufacturer), British Airways, United Kingdom's Civil Aviation Authority (CAA), European Joint Aviation Authorities (JAA), and other organizations representing Austria, France, Germany, Greece, Norway, Poland, and Sweden. The European cabin air study began on January 2001 with an

[29]The European cabin air study is known as CabinAir.

[30]Building Research Establishment, Ltd. (BRE) is a high-level research-based consultancy organization, owned by a not-for-profit entity headquartered in the United Kingdom. BRE provides the aviation industry with expert advice on cabin environment issues and, particularly, on air quality in passenger aircraft.

estimated cost of $8 million and is expected to disclose its findings in 2004.[31]

Of the eight commenting committee members, three addressed the funding of the FAA and ASHRAE surveillance and research programs. These members said that the amount of funding available for U.S. efforts might be insufficient to conduct surveillance and research programs of the scope they envisioned in their recommendations. For example, one of the committee members stated that to conduct a surveillance and research program of the scope the Council had in mind, Congress would have to provide funding levels comparable to that of the European cabin air study.

One commenting committee member, National Institute for Occupational Safety and Health (NIOSH) officials, and airline flight attendant representatives we interviewed expressed concern that the extensive involvement of aircraft manufacturers and airlines in the design and implementation of the FAA and ASHRAE program could threaten the independence of the effort. However, with the exception of the flight attendant representatives,[32] they agreed that any surveillance and research programs require participation by these groups. Nonetheless, they point to the fact that much of the available funding for the initiative ($200,000 of the $250,000) is coming from the aviation industry, which has a stake in the outcome, and that this might give the impression that the study lacks the necessary objectivity. The commenting committee member suggested that the research money provided by the aviation industry be placed in a special fund that would be managed by FAA or an independent research group. According to ATA officials, due to a lack of public funding on a scale comparable to what has been provided for Europe's cabin air study, the financial support and cooperation of aircraft manufacturers and airlines is essential if FAA is to conduct this research. In addition, Boeing officials stressed that the project funding is currently controlled by ASHRAE and the project oversight committee is led by the chairman of the Council study.

[31]In addition to Europe's cabin air study (CabinAir), Australia has addressed cabin air quality issues through the creation of a Reference Group on Cabin Air Quality. The Reference Group is responsible for following the progress of and analyzing the outcomes of international research and development. The Reference Group comprises government agencies, industry representatives, employee/union representatives, and representatives of aircraft and engine manufacturers.

[32]The flight attendant groups have actively lobbied for independent research that is not funded and controlled by companies that have a financial interest in the outcome.

Five of the commenting committee members also discussed the status of their recommendation concerning the need for Congress to designate a lead federal agency and advisory committee for the air quality research effort. Although Congress designated FAA as the lead agency in November 2003, FAA had already assumed responsibility for implementing the research and surveillance-related recommendations. In commenting on the Council recommendation to designate a lead federal agency, several members said they thought that the lead agency should be one that is experienced in conducting scientific research on air quality and environmental health issues. Some noted that the Environmental Protection Agency (EPA) has supported a large body of research into air quality issues, and another pointed out that NIOSH has performed studies of air quality in buildings and the workplace. Several commenting members indicated that although it is FAA's mission to promote aviation safety, they had reservations about whether the agency was well suited to oversee a large air quality research program on its own. Several members thought that, as an alternative, FAA might be part of a cooperative federal effort to perform airliner cabin air quality research. In addition, another committee member believes that although FAA has a committee to oversee the selection of the contractor for the program, it has not assembled an advisory committee to review the research design and monitor the implementation of the program.

Council's Recommendations Concerning FAA Oversight of Aircraft Ventilation Systems

Four of the Council recommendations pertain to FAA's oversight of the operation of aircraft ventilation systems. These recommendations call for FAA to (1) demonstrate in public reports the adequacy of its regulations related to cabin air quality and establish operational standards for ventilation systems, (2) ensure that standards for ozone levels are met on all flights, (3) investigate the need for and feasibility of installing equipment to clean the air supplied to aircraft ventilation systems, and 4) require carbon monoxide monitors in air supply ducts to passenger cabins and establish procedures for dealing with elevated carbon monoxide concentrations. According to FAA officials, the agency originally planned to have an aviation rulemaking advisory committee assess whether current standards were appropriate for ensuring that aircraft ventilation systems adequately prevent contamination of cabin air. However, FAA decided to defer this action until data is available from the surveillance and research study, as well as the European cabin air study. Additionally, FAA believes that data from this study will aid in the reconsideration of air quality standards for commercial aircraft. However, most of the commenting committee members questioned the need for delay in addressing some of the recommendations.

Four of the eight commenting committee members said that they recommended that FAA demonstrate, in public records, the rationale for the established design standards for carbon monoxide (CO), carbon dioxide (CO_2), ozone (O_3), ventilation, and cabin pressure because FAA was unable to explain the reasoning for these standards. For example, FAA has not documented the reasons for setting the ventilation rate standard for aircraft cabins of new aircraft types at .55 pounds of outside air per minute per occupant. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)[33] recommends that ventilation rates inside a building environment be at least 1.1 pounds of outside air per minute per occupant, which is about 50 percent more than the current FAA requirement for aircraft. In addition, FAA has not documented the reasons for requiring a design for cabin air pressure altitude of not more than 8,000 feet air pressure, which is about three-fourths of the air pressure found at sea level. Members of the research community, including the Aerospace Medical Association (AsMA) and CAA, state that the loss of air pressure and oxygen may pose serious health risks for infants whose lungs have not fully developed and for older adults who may have upper respiratory problems.

In response to the committee members' comments, FAA provided us the following explanations for the design standards in question. The ventilation rate standard was based on a regulatory value established decades ago, which has been shown to be acceptable, and ASHRAE has formed a subcommittee to develop a standard specifically for airplanes. The limit for carbon monoxide concentration of 1 part in 20,000 parts air (0.005 percent) was adopted from the Occupational Safety and Health Administration (OSHA) and ASHRAE standards. The limit of maximum allowable carbon dioxide concentration in occupied areas of transport category airplanes was reduced to 0.5 percent in part due to a recommendation from the National Academy of Sciences to review the carbon dioxide limit in airplane cabins; it provides a cabin carbon dioxide concentration level representative of that recommended by some

[33]ASHRAE writes standards and guidelines in its fields of expertise to guide industry in the delivery of goods and services to the public. Currently, it has some 87 active standards and guideline project committees, addressing such broad areas as indoor air quality, thermal comfort, energy conservation in buildings, reduction of refrigerant emissions, and the designation and safety classification of refrigerants.

authorities for buildings. The ozone limits were based on studies conducted by the FAA Civil Aerospace Medical Institute and are comparable to standards adopted by the Environmental Protection Agency and the Occupational Safety and Health Administration. The cabin pressure altitude standard was based on the accepted industry practice of maintaining the health and safety of occupants while considering the structural limitations of the aircraft.

A commenting committee member also expressed concern that FAA certifies aircraft ventilation systems that are designed to meet certain standards, such as those for ventilation rates, but it does not require that systems operate in accordance with these standards. The practical effect is that aircraft are not monitored to determine if they meet the design standards. According to another commenting committee member, FAA did not need data from the planned research project to provide a rationale for ventilation system standards, or to require that ventilation systems operate according to standards. Some committee members also said that FAA could begin to take steps to ensure that ozone standards are met on all flights regardless of altitude and require monitors for dangerous carbon monoxide vapors in air supply ducts to passenger cabins before the completion of the planned research study. FAA officials said that although it does not conduct recurrent system design compliance checks, the agency uses various reporting systems to monitor aircraft system performance and takes appropriate mandatory action when an unsafe condition is found.

Council Recommendation Concerning Airborne Allergens

Because of the potential for serious health effects for people sensitive to allergens, the 2001 Council report also recommended that FAA investigate the need to prohibit the transport of small animals in aircraft cabins and provide training to cabin crews to deal with allergic reactions. However, FAA does not think that prohibiting animals in the cabin would be effective because it believes that most animal allergens are brought onboard aircraft on the clothes of passengers rather than by the animals themselves. Instead, the agency issued an advisory circular highlighting the effective procedures that passengers can use when carrying animals and guidance on how to train crewmembers to recognize and respond to in-flight medical events that result from exposure to allergens. Additionally, FAA will enhance its Internet site to provide general information related to FAA and air carrier policy concerning the transport of animals in aircraft cabins. Commenting committee members generally supported FAA's approach to this recommendation.

Council Recommendation Concerning Health Information

In response to the Council report recommendation calling for FAA to increase efforts to provide cabin crew, passengers, and health professionals with information on health issues related to air travel, FAA modified the general information section of its Web site; however, we found that the traveler health information is not easy to access. FAA created hyperlinks to other Web sites, such as those of the Aerospace Medical Association and Centers for Disease Control and Prevention, which include information on potential health risks of flying, particularly for health-challenged individuals. However, we found it difficult to locate the section of the FAA Web site that deals with traveler health information and when we did, it required several steps to reach the hyperlinks. Some commenting committee members also noted how difficult it is to access health-related information on the FAA Web site. In addition to citing the need for FAA to increase the accessibility of health-related information on its Web site, six of the eight committee members also mentioned that FAA should take further steps to make health information available to the flying public. Suggestions included having airlines include health related information on their Web sites and establishing a program to provide flying-related heath risk information to physicians that they could then share with their patients (e.g., through brochures).

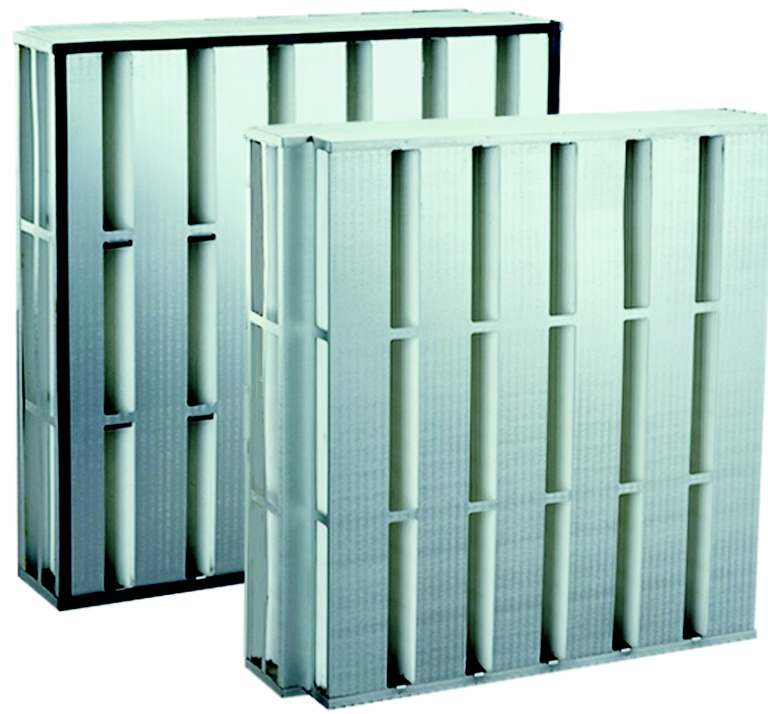
Council Recommendation Concerning Aircraft Ventilation System Shutdown

FAA responded to the 2001 Council report recommendation that it establish a regulation to require removal of passengers from an aircraft within 30 minutes after a ventilation failure or shutdown on the ground by issuing an advisory circular to airlines. Some commenting committee members viewed this action as insufficient. This recommendation reiterated one made in the 1986 Council report, which FAA did not act on. The committees that produced both the 1986 and 2001 reports noted that environmental conditions in an aircraft cabin respond quickly to changes in ventilation system operation. The committees felt that the ventilation system should not be shut down for a long period when the aircraft is occupied, except in the case of an emergency, because excessive contaminant concentrations and uncomfortably high temperatures can occur quickly. Several commenting committee members told us that they felt strongly that FAA should require passenger removal in the event of ventilation system shutdown of more than 30 minutes and that advising airlines that this should be done was insufficient to accomplish the committee's objective. FAA, on the other hand, said that airlines pay close attention to advisories. The agency decided against issuing a regulation because there are situations when an evacuation within 30 minutes is not possible due to operational necessity, such as when a ventilation system breakdown occurs on a taxiway far from a gate.

Some Technologies Exist for Improving Cabin Air Quality, but There Are Questions About Whether They Should be Required

Several technologies exist today that could improve cabin air quality, but opinions vary on whether requiring the use of improved technologies in commercial airliner cabins is warranted. We found one of these technologies, HEPA filters, is strongly endorsed by cabin air quality and health experts as providing the best possible protection against one cabin air problem—the presence of particulates, bacteria, and viruses in recirculated air. While FAA does not currently require HEPA filters, some health experts believe these filters should be required, given their demonstrated effectiveness in cleansing cabin air. Figure 3 illustrates a typical HEPA filter for commercial passenger aircraft.

Figure 3: A Typical HEPA Filter for Commercial Passenger Aircraft



Source: © Donaldson Company, Inc. Reproduced with permission.

According to many in the aviation community, several technologies are available today, and more are in the planning stages, that could improve the air quality in commercial airliner cabins. However, some in the aviation industry question whether requiring their use is warranted. Filtering particulates, bacteria, viruses, and gaseous pollutants and removing ozone can improve the healthfulness of cabin air, and increasing cabin humidity and absorbing more cabin odors and gasses can increase the comfort of passengers and cabin crews. While aircraft manufacturers acknowledge that a few technologies are available today that could further improve air quality and comfort in airliner cabins and that more are possible in the future, they believe that unless future research proves otherwise, the ventilation systems in the aircraft they have produced provide ample amounts of relatively clean air. One technology with proven effectiveness is HEPA filtering of recycled cabin air. All new large commercial airliners in production with ventilation systems that recirculate cabin air come equipped with these filters, which, when properly fitted and maintained, are effective at capturing airborne contaminants such as viruses that enter the re-circulation system. However, some regional jets, which have fewer than 100 seats, are not equipped with filters, and some older large aircraft still use less efficient filters. FAA does not require the filtration of recirculated air, but health experts and members of the committee that produced the 2001 report on cabin air quality believe that given their proven effectiveness, HEPA filters should be required for all aircraft that recirculate cabin air. In addition, airflow rates could be increased in some aircraft by adjusting settings on the ventilation system, thereby dissipating the effects of some contaminants. However, this would be done at the expense of higher fuel consumption, increased engine emissions, and lower cabin humidity.

High Efficiency Particulate Filters Are an Effective Technology for Cleaning Recirculated Air

HEPA filters are a readily available and affordable technology for providing the best possible protection against one cabin air problem—the presence of particulates, bacteria, and viruses in recirculated air. However, HEPA filters will not filter gaseous contaminants. These filters have become widely available for aircraft since the late 1990s. According to EPA, HEPA filters can remove nearly all particulate contaminants, such as airborne particles and infectious agents including bacteria and viruses, from the recirculated air that passes through them.[34] A manufacturer of HEPA filters, as well as health authorities such as CDC, NIOSH, and WHO, believe that HEPA filters are highly effective in preventing the transmission of bacteria and viruses through aircraft ventilation systems. However, they emphasize that HEPA filters clean only the air that is recirculated through aircraft ventilation systems, so transmissions from an infected person to others nearby are still possible.

HEPA filters are available for most large commercial airliners in the U.S. fleet, but some aircraft with recirculation systems are equipped with less effective filters. However, not all commercial aircraft recirculate air through their ventilation systems. For example, some smaller jets, such as

[34]The Environmental Protection Agency states that HEPA filters are to be 99.97 percent efficient for the removal of Particulate Matter (PM) that is greater than or equal to 0.3 micrometer (mm) in diameter.

the Boeing 717 and Bombardier CRJ-200s, which typically fly shorter routes, as well as older models of some longer-range aircraft, such as the Boeing 737-200 and the DC-10, provide 100 percent outside air to the passenger cabins instead of recirculating air and, therefore, would not need HEPA filters. Nevertheless, most commercial airliners in use today recirculate between 30 and 55 percent of the air provided to the passenger cabin. Officials from Boeing and Airbus, the world's two largest manufacturers of commercial aircraft, told us that all their aircraft with recirculation systems currently in production are equipped with HEPA filters. The ventilation systems in many older commercial aircraft were designed to use the less effective filters available at the time, and some of these aircraft still use these types of filters. However, according to Boeing and Airbus officials, HEPA filters can be used on these older aircraft with little or no retrofitting required.[35] According to a filter manufacturer, a HEPA filter costs about twice as much (e.g., $400 to $600 for the smaller narrow-body aircraft) as the non-HEPA models that are less effective in trapping particulates. Some regional jets, such as the Embraer ERJ-145 recirculate air but are not equipped with filters.

In fact, FAA does not require the filtration of recirculated air on aircraft. However, when manufacturers voluntarily equip their aircraft models that recirculate cabin air with HEPA or other filters when they are certified for flight by FAA, as most do, the aircraft are required to continue operating with the filters. The schedule for changing the filters is also included in the FAA certification process. Airlines typically change HEPA filters after 4,000 to 12,000 hours of service to maintain good airflow and in accordance with manufacturers' recommendations.

Little information has previously been available on the extent of HEPA filter usage in commercial aircraft ventilation systems, though the Council report and many in the health community have pointed to the importance of HEPA filters in preventing the spread of bacteria, viruses, and other contaminants in aircraft cabins. As noted earlier in this report, the 2001 Council report recommended that FAA investigate and publicly report on the need for installing equipment to clean the air supplied to aircraft cabin ventilation systems. In the report, the committee did not determine how many larger aircraft were equipped with HEPA filters, and regional jets were not within the scope of its study. However, the report concluded that HEPA filters are highly effective in removing all airborne pathogens and

[35]Installing HEPA filters on the A300 would require some modification.

other particulate matter that pass through them. The report further stated that the use of recirculated air in aircraft cabins when combined with effective HEPA filtration does not contribute to the spread of infectious agents. Members of the research community, including those from NIOSH, as well as the Association of Flight Attendants, have noted that given the proven effectiveness of HEPA filters in capturing contaminants such as infectious viruses and bacteria, FAA should require their use on all aircraft with recirculation systems.

To determine the extent of HEPA filter usage in the United Stares, we surveyed the largest 14 airlines[36] in the United States that had Airbus, Boeing, or McDonnell Douglas aircraft that recirculate cabin air, and we received responses from 12 airlines. Of the 3,038 aircraft for which we were able to obtain survey results, 15 percent (454 aircraft)[37] did not use HEPA filters. All of the aircraft that did not use HEPA filters were older out-of-production models that used less effective filters. One airline has plans to retrofit a small number of these aircraft with HEPA filters.

We were also able to obtain some information on HEPA filter usage in the U.S. regional aircraft fleet by contacting the manufacturers of these aircraft. We found that 69 percent of these regional aircraft recycle cabin air (1,087 of 1,584), and only a handful of these aircraft are equipped with HEPA filters. The manufacturer of a new regional jet model[38] offers HEPA filters as an option. Information we obtained from two airlines that had 29 of these aircraft indicated that about half (14 of 29) were equipped with HEPA filters.

[36]We used revenue passenger miles (RPM) as reported in *Aviation Daily* for May 2003 to identify the largest U.S. carriers. This list identified the largest 28 airlines, 14 of which had the larger aircraft that recirculate cabin air. The other 14 airlines only had smaller regional aircraft or larger aircraft that did not recycle cabin air. An RPM is a standard unit of passenger demand for air transport, defined as one fare-paying passenger transported one mile. We obtained the model information for these carriers from data published in *Air Transport World* (July 2003).

[37]We obtained information on 3,038 larger aircraft that recycled cabin air, 454 of which did not have a HEPA filter. We were not able to obtain survey results for another 384 aircraft. Of these 384, 56 (15 percent) of the aircraft were older models that most airlines had not retrofitted with HEPA filters. Our study included 3,770 larger aircraft, of which 348 did not recycle cabin air.

[38]HEPA filters are available for the CRJ700 manufactured by Bombardier.

We also found that 90 percent of the regional aircraft (973 of 1,087 aircraft) that recycled cabin air would require modifications to be retrofitted with HEPA filters. Most of these aircraft (73 percent) had no provision for installing filters in their air ducts.

Consideration has also been given to filtering outside air entering an aircraft's ventilation system. Outside air at cruise altitudes is mainly free of pollutants, except for ozone. However, in the event of an engine or hydraulic system malfunction, outside air can become contaminated before it enters the ventilation system. In addition, when an aircraft is at the gate or taxiing, the available outside air contains pollutants normally present around the airport, including exhaust from other aircraft on the runway. For these reasons, the 2001 Council report recommended that FAA investigate the need for and feasibility of installing air-cleaning equipment for removing particles and vapors from the air supplied to the ventilation system. As previously noted, FAA has put off consideration of this recommendation until the completion of FAA's and ASHRAE's air quality research and surveillance program in 2006 or 2007. One manufacturer did begin installing outside air filtering equipment on one of its models in 1992. British Aerospace began equipping its BAe 146 aircraft (now out of production) with outside air filters as part of an effort to reduce cabin odors. Other manufacturers, including Boeing and Airbus, contend that outside air filtration is not necessary unless U.S. and European research indicates a problem with the quality of air entering aircraft ventilation systems.

Technology is Available to Remove Ozone from the Air Brought in from Outside the Aircraft

Technologies are currently available for removing ozone from outside air. Ozone is present in the air at high altitudes on some routes, particularly those over the polar regions, and FAA requires that the airlines that fly these routes take measures to maintain cabin ozone levels at or below prescribed limits (e.g., using devices that convert ozone to oxygen). According to ATA officials, nearly all commercial aircraft that fly on these routes are so equipped. However, the Council report said that although FAA requires that ozone concentrations in aircraft cabins be maintained within specified limits, surveillance programs with accurate and reliable equipment are needed to ensure compliance and that the ozone converter equipment works properly. One study attributed elevated ozone levels that exceeded FAA limits to temporary ozone plumes that can appear unexpectedly. In November 2000, the British House of Lords, in a study of health issues in aircraft cabins,[39] made a recommendation that airlines fit their aircraft that fly on routes where these plumes occur with ozone converters to minimize potential health problems. The Council report also identified the need for FAA to take effective measures to ensure that ozone does not exceed levels specified in FAA regulations, regardless of altitude. As noted earlier, FAA plans to monitor ozone levels in selected aircraft as part of its surveillance and research program. However, some committee members told us that the effort will be too limited to enable FAA to determine if ozone is present on aircraft not fitted with converters or whether ozone converters are working properly.

Increasing Ventilation Rates in Aircraft Cabins Poses Challenges

Increasing ventilation rates on aircraft to levels approximating those currently required in buildings would pose technological challenges, and aircraft manufacturers believe such increases are not necessary. Raising ventilation rates would reduce the effects of some airborne contaminants by diluting their concentration.

According to Boeing and Airbus officials, airflow rates on their aircraft could be slightly increased by adjusting settings on the ventilation systems, but such adjustments would increase fuel consumption and result in higher operating costs. According to Boeing officials, to achieve the same airflow rates recommended for buildings, aircraft ventilation systems, and possibly the aircraft themselves, would have to undergo expensive modifications. Boeing and Airbus believe that unless the U.S. and European research and surveillance initiatives prove otherwise, ventilation rates in commercial aircraft are sufficient to sustain passenger and cabin crew comfort and health.

Boeing and Airbus officials told us that they are always seeking to improve the aircraft they build, but they believe that the ventilation systems in the aircraft they produce provide a healthy and relatively comfortable environment for passengers and cabin crew. Nevertheless, Boeing is considering increasing the air pressure and humidity levels on the 7E7, its proposed long-range, high-altitude aircraft. Airbus will also offer an improved air ventilation system on its new large aircraft, the A380. Because of the competitive nature of the aircraft manufacturing industry, few details are available on the 7E7 and A380 ventilation systems. Boeing and Airbus

[39]The House of Lords, Select Committee on Science and Technology, *Air Travel and Health, 5th Report HL.*

officials noted that if current research and surveillance efforts indicate problems with any aspects of the ventilation systems in their aircraft, they would work toward developing the necessary technologies to deal with these problems.

Conclusions

The combined research efforts of FAA and ASHRAE on cabin air quality will provide a foundation of knowledge, according to some members of the committee that produced the 2001 Council report on cabin air quality. However, as currently designed and funded, these efforts may not answer many long-standing questions about the effect of air quality on cabin occupants' health and comfort. FAA is attempting to balance the need to conduct additional research on the healthfulness of cabin air quality with other research priorities, such as improving passenger safety. Our prior work on airliner cabin safety and health has underscored the importance of setting risk-based research priorities, in part by establishing cost and effectiveness estimates to allow direct comparisons among competing research priorities. In commenting on this prior work, FAA cautioned that if too much emphasis is placed on cost/benefit analyses, potentially valuable research may not be undertaken. We concur in that caution. However, information on the nature and extent of health effects from cabin air is needed in order to identify potential health threats so that it can be determined if action is warranted to improve cabin air quality and to target research and development accordingly. Moreover, committee members recommended more study of these issues, and others in the industry have concerns about FAA's surveillance and research program as currently conceived. Committee members were particularly concerned about FAA's decision to delay action on ensuring that air quality regulations are adequate or being met on all flights. In addition, the agency's current plan to monitor cabin air quality on only two aircraft types during part I of its program will not provide FAA with information that is generalizable to the U.S. commercial airliner fleet. Thus, key questions that the agency's research and surveillance program were designed to address will remain unanswered if part II of FAA's program is not properly designed and adequately funded. Such information is also needed to guide the development of new technologies. Given the importance of this research and surveillance effort, the program needs to be well designed, properly funded, coordinated with international cabin air quality research efforts such as those ongoing in Europe and Australia, and conducted in accordance with accepted standards for independence and oversight. The Council in its 2001 report recommended that Congress designate a federal agency to conduct or direct the cabin air quality research program and recent legislation assigned FAA as the lead federal agency for this effort. FAA has begun a surveillance and research program on its own.

Furthermore, FAA has not taken steps to ensure that HEPA filters, which are a proven technology for eliminating some contaminants such as viruses and bacteria from recirculated cabin air, are used as widely as possible on commercial aircraft. FAA does not currently require the use of filters on recirculated air. Nevertheless, we found that a number of aircraft manufacturers and airlines voluntarily install them and that the vast majority of larger commercial aircraft are equipped with HEPA filters. However, we also found that only a few smaller regional jets that recirculate cabin air have HEPA or any other type of filters. FAA has decided to delay addressing the 2001 Council report recommendation calling for the agency to investigate the need for air cleaning equipment on aircraft ventilation systems until it completes its cabin air quality surveillance and research program in 2006 or 2007. FAA needs to determine the costs and benefits of requiring HEPA filters on commercial aircraft that recirculate air.

Finally, although FAA has made some progress in implementing the Council's recommendation regarding the need to increase the availability of information on health issues related to air travel, more needs to be done. Creating links on the FAA Web site to pertinent information on the CDC and WHO Web sites is a good start, but navigating the FAA's Web site to reach these links is difficult. In addition to improving the user friendliness of the FAA Web site links, some commenting committee members suggested that FAA should consider other methods for disseminating information on the health risks of flying, such as providing brochures for physicians to use when discussing these issues with patients.

Recommendations for Executive Action

To help ensure that FAA's research and surveillance efforts on airliner cabin air quality answer critical outstanding questions about the nature and extent of potential health effects of cabin air quality on passengers and flight attendants, GAO recommends that the Secretary of Transportation direct the FAA Administrator to

- develop a detailed plan for the research and surveillance efforts, including key milestones and funding estimates, in accordance with generally accepted practices for oversight and independence;

- appoint a committee of acknowledged experts in the fields of aircraft ventilation and public health, including representatives of EPA and NIOSH, to assist in planning and overseeing the research and surveillance efforts recommended by the National Research Council in 2001;
- leverage the findings of international research on airliner cabin air quality to inform FAA's surveillance and research efforts; and
- report to Congress annually on the progress and findings of the research and surveillance efforts and funding needs.

In order to help improve the healthfulness of cabin air for commercial aircraft passengers and cabin crews, the FAA Administrator should assess the costs and benefits of requiring the use of HEPA filters on commercial aircraft with ventilation systems that recirculate cabin air. If FAA chooses to require the use of HEPA filters, it should also ensure that the regulation covers the maintenance requirements for these filters.

In addition, to increase access to information on the health risks related to air travel, the FAA Administrator should direct the staff responsible for the FAA Web site to improve the links to other Web sites containing this information. The Administrator should also consult with medical associations and health organizations, such as CDC, on other ways to increase the dissemination of this information.

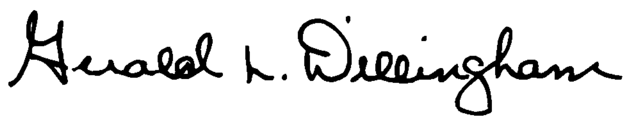
Agency Comments

We provided copies of a draft of this report to the Department of Transportation for review and comment. FAA generally agreed with the report's contents and its recommendations. The agency provided us with oral comments, primarily technical clarifications, which we have incorporated as appropriate.

As agreed with your office, unless you publicly announce the contents of this report earlier, we plan no further distribution until 30 days from the report date. At that time, we will send copies of this report to interested congressional committees, the Secretary of Transportation, and the Administrator, FAA. We will also make copies available to others upon request. In addition, the report will be available at no charge on the GAO Web site at http://www.gao.gov.

Please call me at (202) 512-2834 if you or your staff have any questions concerning this report. Major contributors to this report are listed in appendix VI.

Sincerely yours,



Gerald L. Dillingham
Director, Civil Aviation Issues

Objectives, Scope, and Methodology

The Ranking Democratic Member of the Subcommittee on Aviation, House Committee on Transportation and Infrastructure, asked us to provide information on steps that the aviation community is taking to address concerns about cabin air quality. Specifically, our research focused on the following questions: (1) What is known about the major potential health effects of air quality in commercial airliner cabins on passengers and flight attendants? (2) What actions has the National Research Council recommended to improve cabin air quality, and what is the status of those actions? (3) What technologies are available today to improve the air quality in commercial airliner cabins, and which, if any, should be required?

To answer the first question, we reviewed the December 2001 National Research Council report on aircraft cabin air quality, which was the most current and comprehensive examination of the existing literature on this issue and made recommendations for potential approaches for improving cabin air quality. We also independently reviewed many of the studies on issues related to cabin air quality, paying particular attention to those issued after the publication of the 2001 Council report.[1] We also gathered information from the governments of Australia, Canada, and the United Kingdom and airlines. We also interviewed officials representing the Federal Aviation Administration (FAA), the World Health Organization (WHO), the Centers for Disease Control and Prevention (CDC), the National Institute for Occupational Safety and Health (NIOSH), the Aerospace Medical Association (AsMA), the Air Transport Association (ATA), the Association of Flight Attendants (AFA), the International Airline Passengers Association (IAPA), aircraft and air filter manufacturers, as well as experts on cabin air quality issues, including members of the committee that produced the 2001 Council report on cabin air quality.

To address the second question, we interviewed Council committee members about their views on how FAA was addressing the recommendations they made in their report. Before conducting the interviews, we provided the committee members with information from FAA on its plans for addressing the Council's recommendation. We then asked them for their views on the approach for addressing each of the recommendations. We conducted interviews with 11 of the 13 committee

[1]See the Selected Bibliography at the end of this report and, in particular, Hocking, Martin B., "Trends in Cabin Air Quality on Commercial Aircraft: Industry and Passenger Perspectives," *Reviews on Environmental Health* 17, 1 (2002): 1-49; and Rayman, Russell B., "Cabin Air Quality," *Aviation, Space and Environmental Medicine* 73 (2002): 211-215.

members; we were unable to contact 2 members. Of the 11 members we interviewed, 8 agreed to provide their views on at least some of the recommendations. Three members declined to address any of the recommendations, saying that they were outside their fields of expertise and that they had not followed the progress of FAA's implementation of the recommendations.

To address the third question, we interviewed representatives of aircraft manufacturers, filter manufacturers, FAA officials, and experts on aircraft ventilation systems, including members of the committee. To determine HEPA filter usage, we first identified the 28 airlines that account for 99.94 percent of the revenue passenger miles (RPM) flown by U.S. airlines as reported in *Aviation Daily* for May 2003.[2] Fourteen of these airlines had aircraft that recirculate cabin air. The other 14 only had smaller regional aircraft or larger aircraft that did not recirculate cabin air. After selecting the 28 airlines, we obtained information from *Air Transport World* (Airclaims 2002 data, July 2003 edition) on the number of aircraft they operate by model type. We then obtained information from the aircraft manufacturers that allowed us to categorize the 5,354 aircraft in the 28 airlines by whether or not they recycle air (see table 3).

Table 3: Number of Large and Regional Aircraft of Top 28 Airlines That Do or Do Not Recycle Cabin Air

Aircraft size	Cabin air recycled	Cabin air not recycled	Total
Larger aircraft	3,422	348	**3,770**
Regional aircraft	1,087	497	**1,584**
Total	**4,509**	**845**	**5,354**

Source: GAO.

Larger aircraft included the commercial aircraft manufactured by Airbus, Boeing, and McDonnell Douglas. Regional aircraft included Avions de Transport Regional (ATR), British Aerospace (BAe), Bombardier, Dornier, Embraer, Fokker, Jetstream, and Saab models.

[2]A revenue passenger mile is a standard unit of passenger demand for air transport, defined as one fare-paying passenger transported one mile.

Our primary focus with the larger aircraft was to determine the HEPA filter usage for the 3,422 larger aircraft that recycled cabin air. To obtain this information, we surveyed the 14 airlines that had aircraft in this category and obtained responses from 12 (covering 3,038 of the 3,422 aircraft in this category). Our survey form, which we administered by e-mail, asked the airlines to provide the following information: the number of active aircraft by model type as of June 30, 2003; the number of active aircraft with HEPA filters; the number of active aircraft without HEPA filters; the reasons why HEPA filters are not used; and, if applicable, the types of filters used if other than HEPA filters.

Our primary focus with the regional aircraft was to determine what percentage of these aircraft recycled air, and, for those aircraft that did recycle air, what percentage would require major modifications to be retrofitted with a HEPA filter. We were able to make this determination on the basis of information provided by the manufacturers. Because only a small portion of the regional aircraft that recycle air are capable of being fitted with HEPA filters, we did not survey the 13 airlines that had only regional aircraft. In the cases where returned surveys also included information on regional aircraft that could use HEPA filters with little or no retrofitting, we found that only a small portion were doing so.

Biographical Information on the National Research Council Committee

Dr. Morton Lippman
Professor of environmental medicine and director of the Center for Particulate Matter Health Effects Research and of the Human Exposure and Health Effects Research Program at New York University School of Medicine.

Dr. Harriet A. Burge
Associate professor of environmental microbiology at the Harvard School of Public Health. Dr. Burge's current area of research is on the role of environmental exposures in the development of asthma and evaluating exposure to fungi, dust mite, cockroach, and cat allergens in three separate epidemiology studies assessing risk factors for the development of asthma.

Dr. Byron Jones
Associate dean for Research and Graduate Programs and director of the Engineering Experiment Station at the College of Engineering, Kansas State University. Dr. Jones's research interests are in heat and mass transfer, human thermal systems simulation, and thermal measurements and instrumentation.

Dr. Janet M. Macher
Air pollution research specialist with the Division of Environmental and Occupational Disease Control of the California Department of Health Services. Her research has focused on the evaluation of methods to collect and identify airborne biological material and on engineering measures to control airborne infectious and hypersensitivity diseases.

Dr. Michael S. Morgan
Professor in the Department of Environmental Health, Industrial Hygiene and Safety Program of the University of Washington and director of the Northwest Center for Occupational Health and Safety. His research is focused on human response to inhalation of air contaminants, including the products of combustion and volatile solvents, and has encompassed both ambient air contaminants and occupational environmental health hazards.

Dr. William W. Nazaroff
Professor of environmental engineering in the Department of Civil and Environmental Engineering of the University of California, Berkeley. His main research interest is indoor air quality, with emphasis on pollutant-surface interactions, transport/mixing phenomena, aerosols, environmental tobacco smoke, source characterization, exposure assessment, and control techniques.

Dr. Russell B. Rayman
Executive director of the Aerospace Medical Association in Alexandria, Virginia, retired from the U.S. Air Force in 1989 with the rank of colonel after a military medical career.

Dr. John D. Spengler
The Akira Yamaguchi Professor of Environmental Health and Human Habitation and director of the Environmental Science and Engineering Program at the Harvard School of Public Health. Dr. Spengler's research is focused on assessment of population exposures to environmental contaminants that occur in homes, offices, schools, and during transit, as well as in the outdoor environment.

Dr. Ira B. Tager
Professor of epidemiology in the Division of Public Health, Biology, and Epidemiology at the University of California, Berkeley, and is codirector and principal investigator for the Center for Family and Community Health. Dr. Tager's research includes the development of exposure assessment instruments for studies of health effects of chronic ambient ozone exposure in childhood and adolescence, the effects of ozone exposure on pulmonary function, and the effects of oxidant and particulate air pollution on cardio-respiratory morbidity and mortality and morbidity from asthma in children.

Dr. Christiaan Van Netten
Associate professor in the Department of Health Care and Epidemiology at the University of British Columbia and head of the Division of Occupational and Environmental Health. Dr. Van Netten's research interests include environmental toxicology and the use of electrodiagnostics to monitor worker exposure to agents that affect the peripheral nervous system.

Dr. Bernard Weiss
Professor of environmental medicine and pediatrics at the University of Rochester School of Medicine and Dentistry. His special interest and publications lie primarily in areas that involve chemical influences on behavior, including the neurobehavioral toxicology of metals such as lead, mercury, and manganese.

Dr. Charles J. Weschler
Adjunct professor in the Department of Environmental and Community Medicine at the University of Medicine and Dentistry of New Jersey, Robert Wood Johnson Medical School/Rutgers. His research interests, among others, include chemical interactions among indoor pollutants and the chemistry of the outdoor environment as it impacts the indoor environment.

Dr. Hanspeter Witschi
Professor of toxicology and associate director of the Institute for Toxicology and Environmental Health at the University of California, Davis. Dr. Witschi's research interests include experimental toxicology, biochemical pathology, and the interaction of drugs and toxic agents with organ function at the cellular level.

Source: National Research Council.

Transmission of Severe Acute Respiratory Syndrome (SARS) on Board Aircraft Is Rare and Associated with Proximity

Aboard aircraft, cabin occupants are confined in close quarters for extended periods and can be exposed to infectious diseases carried by other occupants. Because air travel is rapid, people can complete their journeys before the symptoms of a disease begin. Consequently, there has been much concern regarding the in-flight transmission of contagious diseases, particularly tuberculosis and, more recently, severe acute respiratory syndrome (SARS). As part of our review of airliner cabin air quality, we tracked the status of SARS and air travel.

SARS is a serious respiratory illness that has affected persons in Asia, North America, and Europe. According to the World Health Organization (WHO), as of September 26, 2003, there were an estimated 8,098 probable cases reported in 27 countries, including 29 cases in the United States. There have been 774 deaths worldwide, none of which have occurred in the United States. The Centers for Disease Control and Prevention (CDC) believes SARS is caused by a previously unrecognized coronavirus.[1] The symptoms of SARS can include a fever, chills, headache, other body aches, and a dry cough.

SARS appears to be transmitted by close personal contact, which includes touching the eyes, nose, or mouth after touching the skin of infected individuals or objects that have been contaminated with infectious droplets released by an infected individual while coughing or sneezing. People with SARS pose the highest risk of transmission to household members and health care personnel in close contact. Most cases of SARS involved people who cared for or lived with someone with SARS or had direct contact with objects contaminated with infectious droplets. Information to date suggests that people are most likely to be infectious when they have symptoms such as fever or cough. However, it is not known how long before or after their symptoms begin that people with SARS might be able to transmit the disease to others. Most of the U.S. cases of SARS have occurred among travelers returning to the United States from other parts of the world affected by SARS, such as China. According to WHO, as of September 26, 2003, the latest probable case of SARS reported in the United States was on July 13, 2003. However, there is no evidence that SARS is spreading in the United States. WHO has reported that although

[1] A coronavirus is so named because it looks like a corona or halo when viewed under an electron microscope. Two human coronaviruses cause about 30 percent of common colds. Coronavirses have been found to infect cattle, pigs, horses, turkeys, chickens, cats, dogs, rats, and mice.

the global outbreak of SARS has been contained, considerable uncertainty surrounds the question of whether SARS might recur, perhaps according to a seasonal pattern. Several respiratory illnesses occur much less frequently when temperature and humidity are high and then return when the weather turns cooler. WHO has also requested all countries to remain vigilant for the recurrence of SARS and to maintain their capacity to detect and respond to the reemergence of SARS, should it occur. The CDC has conducted broadcasts over the Internet for healthcare providers on preparing for the return of SARS.

WHO has reported that as of May 23, 2003, there have been 29 probable cases of in-flight SARS transmissions on four flights worldwide. Out of the 29 cases, 24 were on one flight, and 4 of the 29 cases were flight attendants. WHO has stated that since then there have been no reported cases of in-flight SARS transmissions. The WHO Director of Communicable Diseases stated there is a very low risk of catching SARS on an airplane through the airplane's ventilation system. He noted that nearly all of the in-flight transmissions occurred between passengers who were sitting near each other. This official also stated that airport screening procedures have been effective in keeping individuals displaying SARS symptoms from boarding aircraft. In October 2003, WHO issued a report in which it did not find evidence that SARS is an airborne disease. This report further stated that at all outbreak sites the main route of transmission was direct contact, via the eyes, nose, and mouth, with infectious respiratory droplets.

In December 2003, the New England Journal of Medicine published the results of a study on the transmission of SARS on three flights that transported at least one person who had SARS.[2] The study found that on one flight carrying four people with SARS symptoms, one other person at most developed the disease, and no illness was documented on another flight transporting a person with presymptomatic SARS. However, on a third flight carrying a symptomatic person, 22 probable cases of SARS[3] occurred among the other 119 passengers. According to the study, for the

[2]Olsen, Sonja J. et al., "Transmission of the Severe Acute Respiratory Syndrome on Aircraft," *The New England Journal of Medicine* 349; 25 (2003): 2416-2422.

[3]According to the study, laboratory confirmed SARS developed in 16 persons, 2 others were given diagnosis of probable SARS and four were reported to have SARS but could not be interviewed by the study team. WHO reported that as of May 23, 2003, 24 probable SARS transmissions occurred on this flight. The study does not indicate the reason for the discrepancy.

22 people with illness, the mean time from the flight to the onset of symptoms was four days, and there were no recognized exposures to persons with SARS before or after the flight. The study found that illness in passengers was related to the physical proximity to the person with SARS on the flight. Illness was reported in 8 of the 23 passengers seated in the three rows in front of the person with SARS, as compared to 10 of the 88 passengers seated elsewhere on the aircraft. The study noted however, that 90 percent of the passengers who became ill on the flight were seated more than 36 inches from the person with SARS, which had been the cutoff used to define the spread of SARS droplets in other investigations. The study authors speculated that "airborne, small particle, or other remote transmission may be more straightforward explanations for the observed distribution of cases." The study concluded that SARS transmissions may occur on flights carrying people in the symptomatic stages of the disease and that measures to reduce the risk of transmission are warranted.

In November of 2003, more than 50 leading SARS researchers from 15 countries concluded that a safe and effective vaccine would be an important complement to existing SARS control strategies. Most of the experts agreed, however, that a SARS vaccine will not be available in time, should an epidemic reoccur in the near future. A WHO official stated that the licensing and commercialization of a SARS vaccine could probably not be realized in 2004.

According to the International Air Transport Association (IATA), passengers are not at risk from being infected with the SARS virus from the cabin crew, who must be medically fit, without SARS symptoms, and physically capable to fly and fulfill their duties. CDC has stated that there is currently no evidence that a person can be infected with SARS from handling baggage or goods, because the primary means of infection is close personal contact. CDC has also stated the transmission of SARS has been associated with close contact with people with SARS symptoms, such as passengers on an aircraft.

The CDC has issued travel alerts and advisories for travel to areas affected by SARS. A travel advisory recommends that nonessential travel be deferred; in contrast, a travel alert informs travelers of the health concern and provides advice about specific precautions. The CDC recommends that if SARS is suspected in an outpatient setting, healthcare providers should provide and place a surgical mask over the person's nose and mouth. The CDC further recommends that if this is not feasible, the person with SARS should be asked to cover his/her mouth with a disposable tissue when coughing, sneezing, or talking. WHO has urged airport officials in countries affected with SARS outbreaks to take precautionary screening measures, such as asking passengers if they have had contact with anyone who has had the disease. U.S. airlines that fly to Asia report that they are following CDC and WHO guidelines. FAA has links to the CDC and WHO guidelines on its Web site. U.S. airlines that do not fly internationally are not modifying their procedures because they see no SARS risk to cabin occupants. According to ATA officials, U.S. airlines that do not fly internationally were not advised by CDC to modify procedures because there was no evidence of community transmission of SARS in the United States. However, all ATA-member airlines cooperated fully with CDC in instances where there was a possible person with SARS who might have transferred from an international to a domestic flight.

European CabinAir Study: Scope and Methodology

In 2001, Building Research Establishment, Ltd. (BRE)[1] initiated a study on cabin air quality that was estimated to cost $8 million. The following link provides the official description of the effort as posted on BRE's Internet site: http://projects.bre.co.uk/envdiv/cabinair/work_programme.html

To further the industry's understanding of what is known about air quality issues by assessing the current level of air quality found in aircraft cabins, BRE will monitor four generic aircraft types in flight and assess cabin air quality and ventilation system performance, including the effects of passenger density and flight duration. A total of 50 such flights are planned. The findings will identify current best practice and will be used to improve understanding of (1) what constitutes good cabin air; (2) the impact on the safety, health, and comfort of passengers and cabin crew; and (3) the effects on operating costs, fuel energy use, and the external environment.

To identify the technology (i.e., environmental control systems including filtration and air distribution) that is available to improve cabin air quality, BRE will develop new designs to address various air quality issues, including the control of carbon dioxide, humidification, outside air supply, and the recirculation and filtration of air. Operating costs and energy consumption will be analyzed in relation to environmental impacts. New designs must be suitable for retrofitting to existing aircraft, either as complete environmental control systems or as subsystems within existing units. The overall intention is to make environmental control systems flexible and easy to operate. For example, improved systems might enable the crew to match the system to the passenger load factor, reduce bleed air, or provide additional comfort in different areas of the cabin.

BRE will seek to improve the performance of filtration systems and then develop new technologies and systems. It will assess existing filtration systems and consider how the installation process and activities such as maintenance, lifting, and cleaning affect performance. A technology demonstrator rig will be developed to test new filtration systems. New and enhanced features will be developed to mitigate such problems as the recirculation of pollutants, bacteria, and viruses. Other major factors

[1]Building Research Establishment, Ltd. (BRE) is a high-level research-based consultancy organization, owned by a not-for-profit entity headquartered in the United Kingdom. BRE provides the aviation industry with expert advice on cabin environment issues and particularly on air quality in passenger aircraft.

include the compatibility of the filtration systems with the overall environmental control system, operational costs, and energy consumption.

The effectiveness of current air distribution systems will be gauged through in-flight monitoring. New design strategies and technologies, such as personal controls, will be developed with the goal of maximizing the effectiveness of cabin ventilation. The study will also look at ways of making the distribution system more easily integrated with aircraft design.

To assess and determine potential improvements to existing standards and performance specifications for the cabin environment, BRE will assess existing standards. Potential improvements to existing standards and specifications will be determined. Checks will be carried out to ensure the feasibility of the performance specifications and costs and to identify any environmental implications. New performance indexes and comfort criteria will also be defined, and BRE will develop a model to be tested.

Surveillance and Research Programs

Key recommendations of the Council report were to establish surveillance and research programs to determine effects of cabin air quality on aircraft occupants' health and comfort.

Surveillance Program

The following is a detailed description of these programs as stated in the Council report.

Surveillance program objectives

- To determine aircraft compliance with existing Federal Aviation Regulations (FARS) for air quality.
- To characterize accurately air quality and establish temporal trends of air-quality characteristics in a broad sample of representative aircraft.
- To estimate the frequency of nonroutine operations in which serious degradation of cabin air quality occurs.
- To systematically document 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.

Surveillance program approach

- Continuously monitor and record ozone, carbon monoxide, and carbon dioxide, fine particles, cabin pressure, temperature, and relative humidity.
- Sample a representative number of flights over a period of 1 to 2 years.
- Continue to monitor flights to ensure accurate characterization of air quality as new aircraft come online and aircraft equipment ages or is upgraded.

- Conduct a program for the systematic collection, analysis, and reporting of health data with the cabin crew as the primary study group.[1]

Research Program

The following is a detailed description of the research program, including long-standing questions regarding air quality, objectives, and program approach.

Outstanding air quality-related questions to be addressed by the research program

- How is the ozone 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 ozone concentrations and health effects on cabin occupants?

- What is the effect of cabin pressure altitude on susceptible cabin occupants, including infants, pregnant women, and people with cardiovascular disease?

- Does the environmental control system (ECS) provide sufficient quantity and distribution of outside air to meet the FAA regulatory requirements, 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 who are in close contact? Does recirculating cabin air increase cabin occupants' risk of exposure?

- What is the toxicity of the constituents or degradation products of engine lubricating oils, hydraulic fluids, and de-icing 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?

[1] On March 4, 2003, FAA announced the creation of a voluntary program for air carriers, called the Aviation Safety and Health Partnership Program. Through this program, the agency intends to enter into partnership agreements with participating air carriers, which will, at a minimum, make data on their employees' injuries and illnesses available to FAA for collection and analysis.

- What are the magnitudes of exposures to pesticides in aircraft cabins, and what is the relationship between the exposures and reported symptoms?
- 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?

Research program objectives

- To investigate possible association between specific air quality characteristics and health effects or complaints.
- To evaluate the physical and chemical factors affecting specific air quality characteristics in aircraft cabins.
- To determine whether FARS for air quality are adequate to protect health and ensure the comfort of passengers and crew.
- 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.

Research program approach

- Use continuous monitoring data from surveillance program when possible.
- Monitor additional air quality characteristics on selected flights as necessary (e.g., integrated particulate-matter sampling to assess exposure to selected contaminants).
- Identify and monitor “problem” aircraft and review maintenance and repair records to evaluate issues associated with air quality incidents.
- Collect selected health data (e.g., pulse-oximetry data to assess arterial oxygen 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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Selected Bibliography

American Society of Heating, Refrigerating and Air-Conditioning Engineers. *Standard 62-2001*, *Ventilation for Acceptable Indoor Air Quality.* Atlanta, GA: 2001.

Barnas, Gary P. *Altitude Sickness: Preventing Acute Mountain Sickness*. Milwaukee, WI: Medical College of Wisconsin, June 4, 1997. http://healthlink.mcw.edu/article/907195877.html (accessed June 19, 2003).

California Department of Health Services, *Occupational Illness Among Flight Attendants Due to Aircraft Disinsection*, California Department of Health Services, http://www.dhs.ca.gov/ohb/OHSEP/disinsection.pdf (accessed Nov. 10, 2003).

Centers for Disease Control. *Updated Interim Domestic Infection Control Guidance in the Health-Care and Community Setting for Patients with Suspected SARS*, Centers for Disease Control, http://www.cdc.gov/ncidod/sars/infectioncontrol.htm (accessed May 13, 2003).

Environmental Protection Agency. *Air Pollution Technology Fact Sheet on High Efficiency Particulate and Ultra low Penetration Air Filters.* Research Triangle Park, NC: July 15, 2003.

Environmental Protection Agency. *Indoor Air Facts Number 4 (revised): Sick Building Syndrome*. Washington, D.C.: February 10, 2003.

Federal Aviation Administration. *Report to the Administrator on the National Research Council Report "The Airliner Cabin Environment and the Health of Passengers and Crew."* Washington, D.C.: February 6, 2002.

Gratz, Norman G., Robert Steffen, William Cocksedge. "Why Aircraft Disinsection?" *Bulletin of the World Health Organization* 78 (8) (2000): 995-1004.

Hocking, Martin B. "Indoor Air Quality: Recommendations Relevant to Aircraft Passenger Cabins." *American Industrial Hygiene Association Journal* 59 (1998): 446-454.

Hocking, Martin B. "Trends in Cabin Air Quality on Commercial Aircraft: Industry and Passenger Perspectives." *Reviews on Environmental Health* 17, 1 (2002): 1-49.

Maresh, Carl M., Lawrence E. Armstrong, Stravos A. Kavouras, George J. Allen, Douglas J. Casa, Michael Whittlesey, and Kent E. LaGrasse. "Physiological and Psychological Effects Associated with High Carbon Dioxide Levels in Healthy Men." *Aviation, Space, and Environmental Medicine* 68, 1 (1997): 41-45.

MedicineNet.com. *Definitions of Bacteria, Virus, and Coronavirus*, MedicineNet.com, http://www.medterms.com/script/main/art.asp?ArticleKey=13954 and http://www.medicinenet.com/script/main/art.asp?li=MNI&ArticleKey=5997&pf=3 (accessed May 12, 2003) and http://www.medterms.com/script/main/art.asp?ArticleKey=22789 (accessed October 14, 2003).

Military Specification. *MIL-E-5007D, General Specifications for Aircraft Turbojet and Turbofan Engines. 1973.*

Nagda, Niren L., Harry E. Rector, Zhidong Li, David R. Space. "Aircraft Cabin Air Quality: A Critical Review of Past Monitoring Studies," *Air Quality and Comfort in Airliner Cabins, ASTM STP 1393*, N. L. Nagda, Ed., American Society for Testing and Materials (2000): 215-239.

National Research Council. *The Airliner Cabin Environment: Air Quality and Safety.* National Academy Press. Washington, D.C.: 1986.

National Research Council. *The Airliner Cabin Environment and the Health of Passengers and Crew.* National Academy Press. Washington, D.C.: Distributed electronically December 2001; bound report copyrighted 2002.

Olsen, Sonja J. et al. "Trasmission of Severe Acute Respiratory Syndrome on Aircraft." *The New England Journal of Medicine* 349; 25 (2003): 2416-2422.

Parliament of the Commonwealth of Australia. Rural and Regional Affairs and Transport References Committee. Australian Senate *Air Safety and Cabin Quality in the BAe 146 Aircraft.* Canberra: 2000.

Rayman, Russell B. "Cabin Air Quality." *Aviation, Space and Environmental Medicine* 73 (2002): 211-215.

Society of Automotive Engineers. *ARP 4418, Procedure for Sampling and Measurement of Engine Generated Contaminants in Bleed Air Supplies from Aircraft Engines Under Normal Operating Conditions*. Warrendale, PA: 1995.

Society of Automotive Engineers. *ARP 1270, Aircraft Cabin Pressurization Control Criteria*. Warrendale, PA: 2000.

The House of Lords, Select Committee on Science and Technology. *Air Travel and Health,5th Report HL Paper 121-I.* Session 1999-2000. London: 2000.

U.S. Department of Transportation, Office of the Inspector General. *Further Delays in Implementing Occupational Safety and Health Standards for Flight Attendants Are Likely.* AV-2001-102. Washington, D.C.: September 26, 2001.

U.S. General Accounting Office. *SARS Outbreak: Improvements to Public Health Capacity Are Needed for Responding to Bioterrorism and Emerging Infectious Diseases.* GAO-03-769T. Washington, D.C.: May 7, 2003.

U.S. General Accounting Office. *Serve Acute Respiratory Syndrome: Established Infectious Disease Control Measures Helped Contain Spread, But a Large Scale Resurgence May Pose Challenges.* GAO-03-1058T. Washington, D.C.: July 30, 2003.

U.S. General Accounting Office. *Aviation Safety: Advancements Being Pursued to Improve Airliner Cabin Safety and Health.* GAO-04-33. Washington, D.C.: October 3, 2003.

World Health Organization. *International Travel and Health*, World Health Organization, http://www.who.int/ith/chapter02_01.html (accessed July 24, 2003).

World Health Organization. *Tuberculosis and Air Travel: Guidelines for Prevention and Control* World Health Organization, http://www.who.int/gtb/publications/aircraft/ (accessed Oct. 1, 2003).

Zitter, Jessica, Peter Mazonson, Dave Miller, Stephen Hulley, and John Balmes. “Aircraft Cabin Air Recirculation and Symptoms of the Common Cold.” *Journal of the American Medical Association* 288 (2002): 483-486.

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