

GAO

Report to the Honorable
James L. Oberstar, Ranking Democratic
Member, Committee on Transportation
and Infrastructure, House of
Representatives

February 2000

AVIATION AND THE ENVIRONMENT

Aviation's Effects on
the Global
Atmosphere Are
Potentially Significant
and Expected to Grow



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Abbreviations

EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
GAO	General Accounting Office
ICAO	International Civil Aviation Organization
IPCC	Intergovernmental Panel on Climate Change
NASA	National Aeronautics and Space Administration
NOx	A combination of nitric oxide and nitrogen dioxide



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

Resources, Community, and
Economic Development Division

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February 18, 2000

The Honorable James L. Oberstar
Ranking Democratic Member
Committee on Transportation
and Infrastructure
House of Representatives

Dear Mr. Oberstar:

Concerns about global warming are focusing increasingly on the contribution of human activities, including aviation. Jet aircraft are among many sources of greenhouse gases—gases that can trap heat, potentially increasing the temperature of the earth's surface and leading to changes in climate.^{1,2} According to a recent report by the National Research Council, the average global temperature at the earth's surface has risen 0.7 to 1.4 degrees Fahrenheit over the last century.³ Many experts agree that, in total, greenhouse gases are warming the earth and that this warming could have harmful effects on the environment and human health.⁴ For example, some scientists are concerned that with global warming, glaciers and ice sheets could melt, leading to a rise in sea levels and subsequent coastal flooding. In addition, they expressed concern that the incidence of malaria and other tropical infectious diseases could increase in moderate climates.

¹Our report focuses on the effects of subsonic jet aircraft engine emissions on the upper atmosphere—above 3,000 feet—and does not address the effects of these emissions on local air quality. A recent international review of aviation and the global atmosphere had a similar focus.

²We focused on commercial civilian subsonic jet aircraft because they account for the majority of aviation emissions; military and general aviation aircraft account for the remainder. In the commercial fleet, fewer than 15 civilian supersonic jets currently operate worldwide. Throughout this report, we use the terms “aviation” and “jet aircraft” interchangeably.

³*Reconciling Observations of Global Temperature Change*, Panel on Reconciling Temperature Observations, National Research Council (Jan. 2000).

⁴Greenhouse gases emitted by jet aircraft include carbon dioxide and water vapor. Other emissions from aircraft—nitric oxide and nitrogen dioxide (NOx) and soot and sulfate particles—are not greenhouse gases, but are able to produce gases (i.e., ozone) or other agents (i.e., clouds) that do act as greenhouse gases. In combination, all of these aviation emissions are believed to have a net warming effect on the earth's surface.

While aviation is believed to contribute less to global warming than some other human activities, it is one of the fastest-growing sectors of the world economy, with global air passenger travel projected by some experts to grow 5 percent annually from 1990 through 2015. Hence, the impact of aircraft emissions on the earth's atmosphere and climate is a concern for transportation planners and policymakers.

Anticipating rapid growth in global air travel and potentially increasing environmental effects from aircraft emissions, you asked us to provide information on (1) what is currently known about aviation's contribution to global warming and how aviation emissions, both domestic and global, compare with emissions from other sources and (2) what options are available for reducing aviation emissions. This report is based on our review of current research and interviews with experts in the aviation, scientific, and environmental communities on issues related to aviation and global warming. In particular, we relied on a recent report on aviation and the earth's atmosphere issued by the Intergovernmental Panel on Climate Change under the auspices of the United Nations. Although we did not independently evaluate the research in this report, it was reviewed by over 150 experts worldwide and is generally considered the most comprehensive and up-to-date information on the subject. (See app. I for more detailed information on our scope and methodology.)

Results in Brief

Aviation emissions comprise a potentially significant and growing percentage of human-generated greenhouse gases and other emissions that are thought to contribute to global warming. The Intergovernmental Panel on Climate Change recently estimated that global aircraft emissions accounted for approximately 3.5 percent of the warming generated by human activities. Of the various emissions generated by aviation, scientists know a great deal about carbon dioxide, which is the primary aircraft emission, but less about the other emissions. As a result, the scientific community has identified areas that need further study to enable them to more precisely estimate aviation's effects on the global atmosphere. As for the contributions of U.S. aviation relative to other U.S. industrial sources, data from the Environmental Protection Agency show that in 1997, aviation accounted for about 3 percent of U.S. greenhouse gas emissions. This compares with 23 percent for other transportation sources and 41 percent for other industrial sources. Global aviation emissions of carbon dioxide (measured in million metric tons of carbon) are a small percentage of carbon emissions worldwide; however, they are roughly equivalent to the carbon emissions of certain industrialized countries. According to data

from a 1999 report of the Intergovernmental Panel on Climate Change, global aviation contributed about 145 million metric tons of carbon in 1996, or about 2.4 percent of all human-generated carbon emissions—an amount roughly equivalent to the total carbon emissions of Canada.

Aircraft emissions are potentially significant for several reasons:

- Jet aircraft are the primary source of human emissions deposited directly into the upper atmosphere. The Intergovernmental Panel on Climate Change and experts noted that some of these emissions have a greater warming effect than they would have if they were released in equal amounts at the surface—by, for example, automobiles.
- Carbon dioxide is relatively well understood and is the main focus of international concern. According to the Intergovernmental Panel on Climate Change, it survives in the atmosphere for about 100 years and contributes to warming the earth. Moreover, as noted, global aviation's carbon dioxide emissions (measured in million metric tons of carbon) are roughly equivalent to the carbon emissions of certain industrialized countries.
- Carbon dioxide emissions combined with other gases and particles emitted by jet aircraft—including water vapor, nitrogen oxide and nitrogen dioxide (collectively termed NO_x), and soot and sulfate—could have two to four times as great an effect on the atmosphere as carbon dioxide alone. According to the Intergovernmental Panel on Climate Change the atmospheric effects of these combined emissions will require further scientific study.
- The Intergovernmental Panel on Climate Change recently concluded that the increase in aviation emissions attributable to a growing demand for air travel would not be fully offset by reductions in emissions achieved through technological improvements alone.

Experts in the aviation, scientific, and environmental communities agree that the aviation industry will continue to grow globally and contribute increasingly to human-generated emissions. The experts differ, however, in the rates of growth they project and the effects they anticipate.

Recognizing aviation's potentially significant impact on the global atmosphere, experts we interviewed and the report of the Intergovernmental Panel on Climate Change identified a range of options to better understand and mitigate aviation's impact as the industry grows. These options include (1) continuing research to improve the scientific understanding of aviation's effects on the global atmosphere as a basis for

guiding the development of aircraft and engine technology to reduce these effects, (2) promoting more efficient air traffic operations through the introduction of new technologies and procedures, and (3) expanding the use of regulatory and economic measures to encourage reductions in emissions. Governments are pursuing these options, although they have not agreed on specific regulatory and economic measures.

Background

Human activities, primarily those related to producing and using energy, are increasing concentrations of the heat-trapping greenhouse gases that many experts believe are warming the planet. According to the Intergovernmental Panel on Climate Change (IPCC),⁵ when greenhouse gases are added to the atmosphere, they increase the effectiveness of the earth's atmospheric blanket, warming the earth's surface and potentially leading to changes in climate. Greenhouse gases are produced through both natural activities (e.g., decaying organic matter) and human activities (e.g., manufacturing and transportation). Greenhouse gas levels in the atmosphere are the net result of processes that generate greenhouse gases (sources) and processes that destroy or remove them (sinks). The ability to accurately quantify the current impact of human activity on the global climate is limited by a lack of understanding about how much the climate would vary without these activities. Also uncertain, because of incomplete scientific understanding, is how the atmosphere and climate system will react to human-induced changes in greenhouse gas concentrations over the long term. According to the IPCC, to date, the balance of the evidence suggests that there is a discernable human influence on the global climate.

⁵The IPCC was established by the United Nations Environment Programme and the World Meteorological Organization to assess information on the science, impacts, economics, and options for mitigating and adapting to climate change.

Global aviation is the first industrial subsector whose potential impact on the global atmosphere has undergone an international assessment by the IPCC. According to the IPCC, this assessment was important because the aviation industry has grown rapidly and become an integral and vital part of modern society. The Air Transport Action Group reported that the aviation industry contributed \$1,140 billion in annual gross output to the global economy in 1994⁶—a contribution that is expected to increase to \$1,800 billion by 2010. Increased environmental impact can be expected to accompany this increased economic activity. To its credit, the aviation industry is working with the U.S. government, the International Civil Aviation Organization, and other international organizations to assess and manage the effects of aviation on the environment.

International concerns about the contribution of human activities, including aviation, to global climate change have led to several efforts to reduce their impact. For example, in 1992, 155 nations, including the United States, signed the United Nation's Framework Convention on Climate Change—a convention designed to stabilize concentrations of greenhouse gases in the atmosphere at a level that would prevent human activities from interfering dangerously with the climate system. By 1995, parties to the convention, including the United States, realized that progress toward this goal was not sufficient. In December 1997, the parties reconvened in Kyoto, Japan, to establish binding measures to reduce greenhouse gas emissions. Under the resulting Kyoto Protocol, 38 developed nations (the United States, France, Japan, and others) pledged to reduce their emissions of carbon dioxide and other greenhouse gases from 2008 through 2012. The protocol directed the parties to work through the International Civil Aviation Organization (ICAO) to reduce or limit emissions from aviation.

⁶The Air Transport Action Group is an independent coalition of organizations with a worldwide membership that includes airlines, airports, pilots, air traffic controllers, and manufacturers, among others. Air Transport Action Group, *The Economic Benefits of Air Transport: 1994 Data* (Mar. 1997).

If the U.S. Senate ratifies the protocol, the United States could be required to significantly reduce its greenhouse gas emissions. Specifically, the United States agreed in the protocol to reduce its annual emissions, during the 5-year period from 2008 through 2012, to a level 7 percent below the 1990 emissions level. To achieve this new level, the United States may have to cut projected emissions levels by 31 percent by 2010 (the midpoint of the 5-year period)—a reduction equivalent to about 548 million metric tons of carbon.⁷ In addition, the United States, along with other parties to the protocol, is already required under the Framework Convention on Climate Change to report periodically to the secretariat of the convention on its greenhouse gas emissions, plans for developing programs to mitigate climate change, and strategies for adapting to the impact of climate change. The Kyoto Protocol would add the requirement that parties to the protocol establish national systems for estimating greenhouse gas emissions using methodologies adopted by the parties to the protocol and estimate and report their emissions estimates annually. In addition, under the protocol, emissions targets would be established and participants would be allowed to use a market-based mechanism for trading emissions credits.⁸

In an effort to understand the impact of aviation emissions on the global atmosphere, ICAO and parties to the Montreal Protocol on Substances that Deplete the Ozone Layer⁹ requested that the IPCC assess the effects of aircraft on climate and atmospheric ozone. A group of over 100 international experts reviewed the most current research available and incorporated the findings into a report entitled *Aviation and the Global Atmosphere*.¹⁰ This report then went through a rigorous peer review process that involved 150 international academic, technical, and scientific experts; nongovernmental organizations; and industry before being published in 1999. Throughout this process, the participants attempted to develop a consensus view on the effects of aviation on the global atmosphere. ICAO will consider the results of this report as it addresses its

⁷Energy Information Administration, *International Energy Outlook 1999* (Mar. 1999).

⁸Such trading allows parties to exchange emissions credits to meet an environmental goal. Parties that exceed emissions requirements can thus trade with others that are operating below emissions requirements to achieve compliance at a lower overall cost.

⁹The Montreal Protocol on Substances that Deplete the Ozone Layer, as amended, is an international agreement established in 1987 to phase out the use of chlorofluorocarbons and other ozone-depleting substances.

¹⁰*Aviation and the Global Atmosphere*, IPCC (1999).

responsibilities under the Kyoto Protocol to reduce greenhouse gas emissions from international aviation.

Aviation's Effects on the Global Atmosphere Are Potentially Significant

The IPCC estimated aviation's impact on global warming on the basis of emissions that aviation generates. However, scientific understanding of the impact of aviation emissions on global warming varies. For example, the influence of carbon dioxide is well understood, while the effects of other aircraft emissions, such as nitric oxide and nitrogen dioxide (commonly referred to as NO_x), are less certain. In the United States, aviation's contribution to increases in human-generated greenhouse gases is about 3 percent and can be compared with the contributions of other U.S. industrial sources. Higher greenhouse gas levels are, in turn, thought to contribute to global warming. Global aviation's carbon dioxide emissions (measured in million metric tons of carbon) are a small percentage of carbon emissions worldwide; however, they are roughly comparable to the contributions of certain industrialized countries. Some experts believe that aviation's emissions are potentially significant, in part because some aircraft emissions deposited directly into the upper atmosphere are thought to have a greater warming effect than the same volume of emissions generated at ground level. In addition, the scientific, aviation, and environmental communities agree that the global aviation industry will continue to grow well into the next century. However, they disagree on the pace of growth relative to that of the world economy as a whole and, thus, on whether global aviation will contribute an increasing proportion of human-generated climate effects.

The IPCC Estimated Global Aviation's Contribution to Global Warming

To estimate global aviation's impact on global warming, and, hence, on climate change relative to other human sources, the IPCC used the concept of radiative forcing—a measure of the importance of a potential climate change mechanism in affecting the heat balance of the earth's atmospheric system.¹¹ The 1999 IPCC report estimated that global aviation contributed 3.5 percent of human-generated radiative forcing (warming) in 1992.¹² The IPCC further estimated that by 2050, aviation's contribution could increase to 5 percent of the total human-generated radiative forcing. According to the IPCC, when measured in watts per square meter, the increase in warming attributable to aviation alone is projected to be over 260 percent between 1992 and 2050.¹³ In terms of climate change, the IPCC estimated an increase in the earth's temperature of approximately 1.6 degrees Fahrenheit by 2050, of which about 0.09 degrees would be attributable to aviation.^{14,15} However, it should be noted that the earth's average temperature has risen only about 7 degrees Fahrenheit since the last ice age. According to officials from the National Aeronautics and Space Administration (NASA), the projection that aviation's contribution would increase to only 5 percent by 2050 assumes a robust contribution from technology that would increase fuel efficiency and reduce NOx emissions.

¹¹Radiative forcing, in watts per square meter, measures the impact on climate (warming or cooling) of changes in greenhouse gases, aerosols, and clouds.

¹²In 1992, the IPCC developed several scenarios that included the contributions of greenhouse gases from all sectors. These scenarios were inherently uncertain because they incorporated assumptions—to project warming trends worldwide—about future economic and population growth, technological changes, and land use. The authors of the 1999 IPCC report on aviation started with these projections and built a new scenario specifically for aviation growth based on key assumptions about economic and population growth contained in the 1992 scenario. Experts believe the 1992 scenario is still applicable. Throughout the report, the IPCC uses a mid-range estimate to illustrate the possible effects of aircraft emissions on the atmosphere.

¹³According to the IPCC, aviation contributed about 0.05 watts per square meter in 1992, and its contribution is estimated to increase to approximately 0.19 watts per square meter by 2050—an increase of 263 percent.

¹⁴According to an IPCC expert, the authors of the report were able to estimate the temperature change associated with aviation's future contribution because they used the same variables over the same time period, allowing for a more direct calculation. By contrast, calculating the temperature change for the past would have been much more difficult because of the complexity of making the calculation, the large number of variables involved, and the resulting lack of confidence in the outcome.

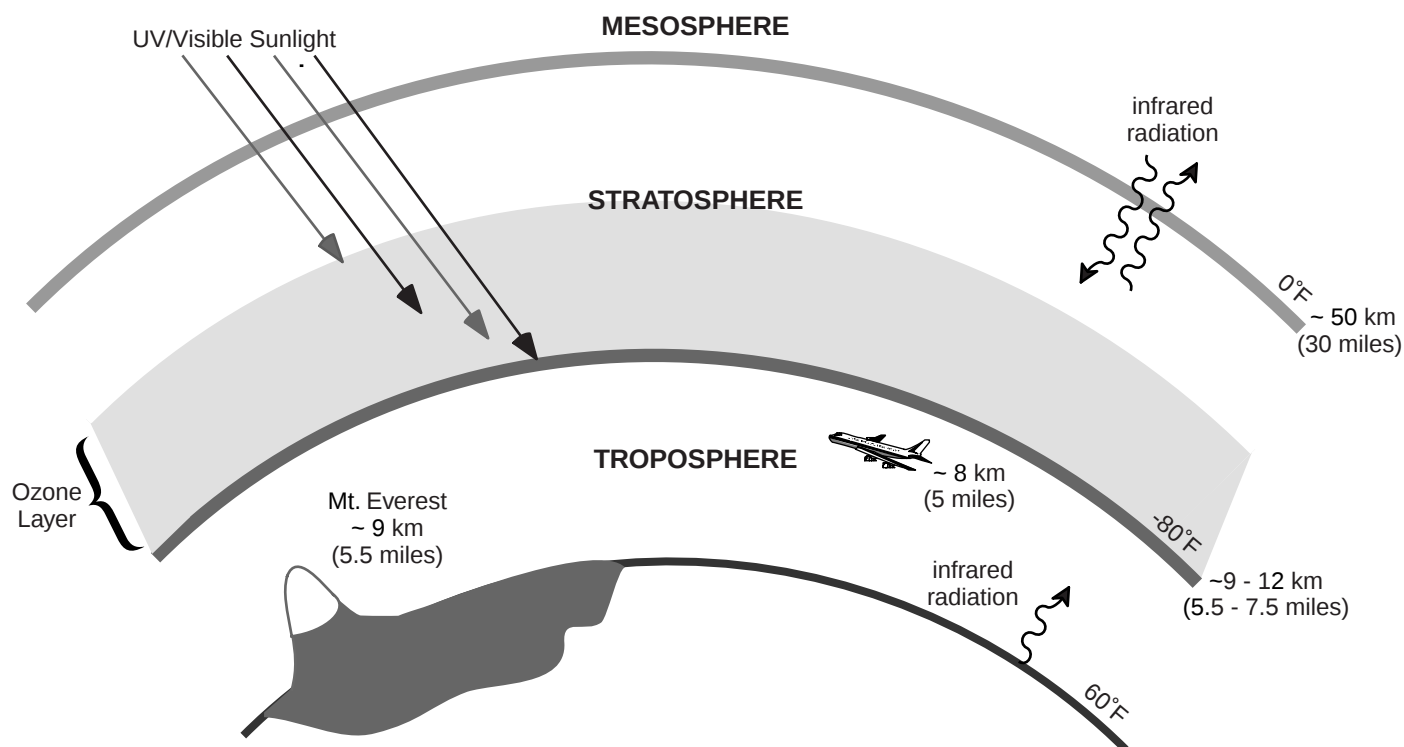
¹⁵The IPCC used the scenarios discussed in footnote 12 to estimate these temperature changes.

They noted, however, that achieving these reductions would require significant improvements in technology that are not currently funded.

Scientific Understanding of Aviation Emissions Varies

The IPCC experts agree on the types of emissions from jet aircraft that may contribute to a warming of the earth's surface but know more about the impact of carbon dioxide than of the other emissions. Jet aircraft deposit most of their emissions at cruise altitudes, primarily in the troposphere—altering concentrations of greenhouse gases directly by emitting carbon dioxide and indirectly by emitting NO_x. In addition, emissions of water vapor and soot and sulfate particles have both direct and indirect effects. See figure 1 for an overview of the layers of the atmosphere, including the altitudes flown by jet aircraft.

Figure 1: Layers of the Atmosphere



Source: The National Oceanic and Atmospheric Administration's Aeronomy Laboratory.

According to the IPCC report, the atmospheric effects of carbon dioxide emissions from jet aircraft are relatively well understood. Carbon dioxide emissions remain in the atmosphere for about 100 years and contribute to a warming of the earth's surface. Scientists estimate that as a result of human activity, the level of carbon dioxide in the atmosphere has risen by almost 30 percent since pre-industrial times (e.g., about 250 years ago). In addition, carbon dioxide becomes well mixed throughout the atmosphere, meaning that the total impact of carbon dioxide on the climate will be the same irrespective of the point of origination. (See app. II for the levels of scientific understanding of aviation's impact on the global atmosphere.)

The impact of other aviation emissions on the global atmosphere is less certain. Such emissions include the gases NO_x, water vapor, and, to a lesser extent, soot and sulfate particles (aerosols) that result, in part, from the incomplete combustion of jet fuel. While the IPCC states that scientists cannot calculate the precise impact of these gases and particles, it maintains that in certain layers of, or locations in the atmosphere, the gases and particles in combination have a warming effect. Moreover, according to the IPCC, the atmospheric effects of these aircraft-related gases and particles in combination with carbon dioxide could be two to four times greater than the atmospheric effects of carbon dioxide alone.

Current scientific models predict that NO_x, in combination with water vapor and sulfate, depletes ozone—a greenhouse gas—in the mid-and upper stratosphere. In contrast, NO_x increases ozone in the troposphere and lower stratosphere, warming the earth's surface by trapping radiation as it is being reflected back toward space. These increases in ozone are the primary effects of NO_x emissions. However, increases in NO_x emissions also reduce methane—another greenhouse gas.¹⁶

In the troposphere, precipitation quickly removes emissions of water vapor—a greenhouse gas. However, in the lower stratosphere, water vapor emissions can build up and lead to higher concentrations that, in turn, are predicted to warm the earth's surface. Water vapor can enhance the formation of contrails—the thin white-line clouds often seen behind jet

¹⁶Methane is a greenhouse gas with many natural and human sources. According to the IPCC, reducing its concentration in the atmosphere leads to cooling. However, the warming effect resulting from increases in ozone in the troposphere offsets the cooling effect of reductions in methane attributable to aviation—resulting in a net warming.

aircraft—that are also expected to warm the earth’s surface. In addition, extensive cirrus clouds have been observed to develop after the formation of persistent contrails. These increases in cirrus cloud cover have been positively correlated with aircraft emissions in a limited number of studies. On average, an increase in cirrus cloud cover tends to warm the earth’s surface. Finally, increases in particles emitted by aircraft have mixed effects: Soot tends to warm the earth’s surface, while sulfate particles tend to cool it. While the direct effects of these particles are believed to be small, increases in their emissions by jet aircraft may potentially influence the formation of clouds in the upper atmosphere. This, in turn, may contribute to future climate change. Given the limited scientific understanding of the impact of many aviation emissions—in particular, their influence on cirrus cloud formation—experts noted that further research would help to clarify and more accurately quantify aviation’s impact on the global atmosphere and contribution to climate change.

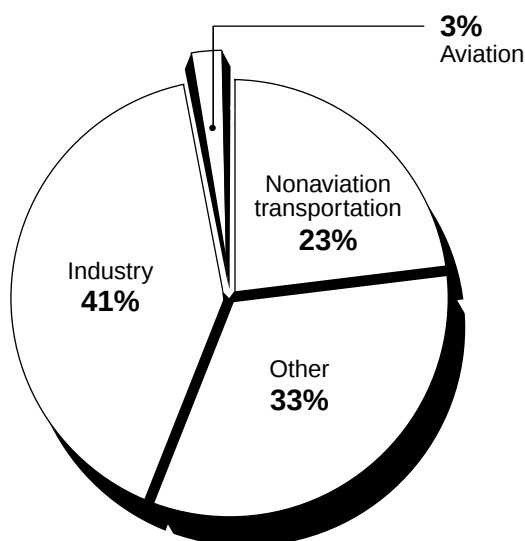
Contributions of U.S. and Global Aviation Emissions Can Be Compared With Contributions of Emissions From Other Sources

The relative impact of aviation emissions on the global atmosphere can be assessed by comparing (1) greenhouse gas emissions from U.S. aviation and other U.S. industrial sources and (2) carbon emissions (measured in million metric tons of carbon) from global aviation and industrialized countries.

The relative contributions to greenhouse gases from U.S. aviation and other U.S. industrial sources can be estimated by comparing the amounts of emissions generated by each source. According to the most recent data available from the Environmental Protection Agency (EPA), in 1997, greenhouse gas emissions from U.S. aviation accounted for about 3 percent of the total U.S. greenhouse gas emissions from human sources, while the remainder of the transportation sector accounted for approximately 23 percent.¹⁷ Passenger cars and light duty trucks were responsible for well over half of these emissions. In comparison, other industrial sectors accounted for approximately 41 percent of the total U.S. greenhouse gases from human sources, and other miscellaneous sources accounted for the remaining 33 percent.¹⁸ (See fig.2)

¹⁷EPA measured the greenhouse gases carbon dioxide, methane, nitrous oxide, and hydrofluorocarbons for transportation-related emissions. Carbon dioxide emissions from international passenger and cargo aviation are reported separately as bunker fuels and are not included in the U.S. totals. See *Inventory of U.S. Greenhouse Gas Emissions and Sinks; 1990-1997*, EPA (Apr. 1999).

¹⁸For the industrial sector, EPA measured the four gases emitted by the transportation sector plus two other gases, PFCs and SF₆, which are not emitted by the transportation sector. Sources in the "other" category include such things as landfills and wastewater treatment facilities. See EPA's Apr. 1999 report.

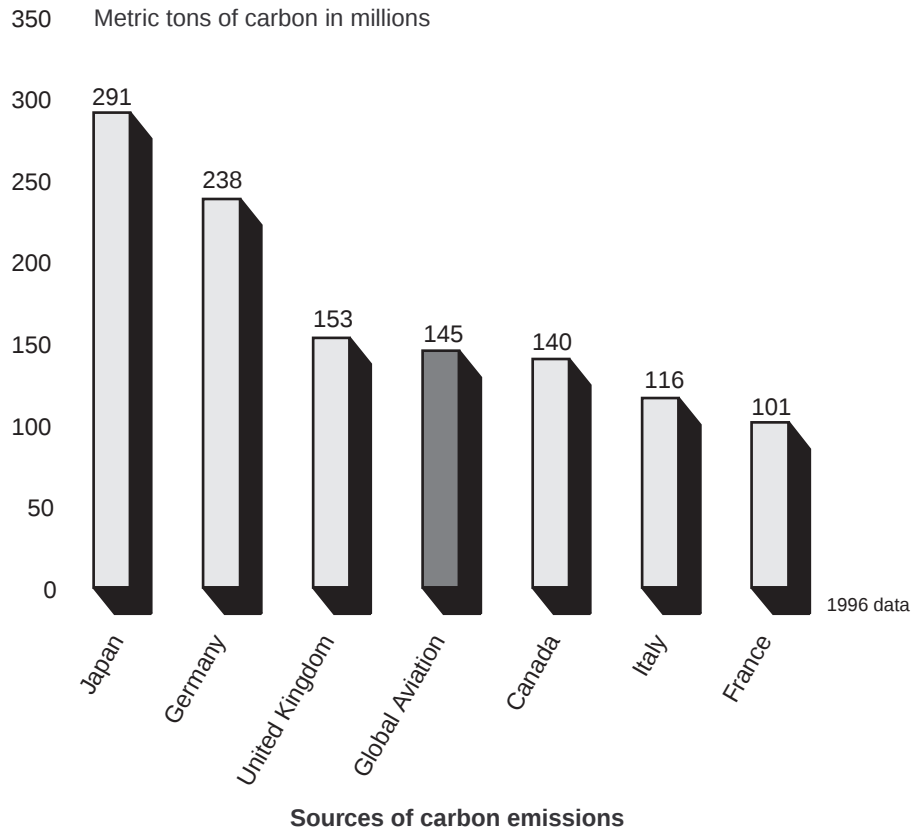
Figure 2: Greenhouse Gas Emissions From U.S. Aviation and Other U.S. Sources

Source: GAO's analysis of data from EPA.

Carbon dioxide emissions result from the burning of fossil fuels and are the primary component of aviation emissions.¹⁹ Globally, aviation-related carbon dioxide emissions (measured in million metric tons of carbon) can be compared with the carbon emissions of some industrialized countries (also measured in million metric tons of carbon). For example, according to data from the 1999 IPCC report, global aviation produced about 145 million metric tons of carbon, or about 2.4 percent of all human-generated carbon emissions in 1996. In the same year, Canada's total carbon emissions were 140 million metric tons, or also about 2.4 percent of the world's total carbon emissions, and the United Kingdom's were 153 million metric tons, or about 2.6 percent of the world's total. (See fig. 3.) While these individual percentages are small, collectively they add to the world's total carbon emissions, which are known to have a warming effect on the earth.

¹⁹Fossil fuels include coal, oil, and natural gas that are formed in the earth from plant or animal remains.

Figure 3: Total Carbon Emissions From Global Aviation and Selected Industrialized Countries



Notes:

In 1996, the United States produced 1,463 million metric tons of carbon, or about 24 percent of the world's total.

As mentioned earlier, the focus of our report is civil global aviation, which accounted for about 145 million metric tons of carbon in 1996. However, if total global aviation (including military operations) is included, the figure rises to about 170 million metric tons of carbon.

Sources: *International Energy Outlook*, Energy Information Administration (1999) and *Aviation and the Global Atmosphere*, IPCC (1999).

Some Experts Believe That Aviation's Effects on the Global Atmosphere Are Potentially Significant

According to some experts, aviation's contribution to human-generated emissions and its effects on the global atmosphere are potentially significant for several reasons. First, jet aircraft are the major source of human emissions deposited directly into the upper atmosphere. The IPCC and experts noted that when these emissions are released into the upper

atmosphere, some of them have a greater warming effect than when they are released in the same amounts at the surface, by sources such as automobiles. Next, carbon dioxide—aviation’s primary emission—is the central focus of international attention because, as the IPCC noted, it has a long atmospheric life span (about 100 years) and has a warming effect on the earth’s surface. Furthermore, the carbon dioxide emissions (measured in million metric tons of carbon) of global aviation are roughly equivalent to the carbon emissions of selected industrialized countries.

In addition, according to the IPCC, jet aircraft flying at cruise altitudes also emit other atmospheric gases (water vapor and NO_x) and particles (soot and sulfate) whose effects are not as well understood as carbon dioxide’s. However, the combined effects of carbon dioxide and these gases on the atmosphere could be two to four times greater than the effects of carbon dioxide alone. Furthermore, the IPCC recently concluded that the increases expected in aviation emissions from a growing demand for air travel would not be fully offset by technological improvements alone.

An EPA official noted that aviation’s contribution to U.S. emissions of carbon dioxide is small compared with the contributions of electric utilities and automobiles, which are substantially larger. In addition, officials from both EPA and the Federal Aviation Administration (FAA) told us that aviation contributes as much or more than some industrial subsectors—including the chemical, iron and steel, and cement-manufacturing subsectors.

Aviation's Effect on Greenhouse Gases Is Expected to Grow, but Experts Differ on the Magnitude of Growth

The scientific, aviation, and environmental communities agree that the global aviation industry will continue to grow well into the next century and its operations will result in increased emissions and environmental effects. However, they disagree on the pace at which aviation will grow relative to that of the world economy, especially when projected 50 years into the future. They also disagree on whether global aviation will contribute an increasing proportion of human-generated climate effects. The IPCC report used a range of scenarios to estimate future air passenger demand. These included a high-range scenario that projected annual growth of 4.7 percent between 1990 and 2050, a mid-range scenario that projected annual growth of 3.1 percent, and a low-range scenario that projected annual growth of 2.2 percent.^{20,21}

While some environmental groups from the United States and Europe have expressed concern that the mid-range estimate to 2050 was understated, some in the aviation industry found the estimate overstated.²² Specifically, some of the aviation industry representatives we interviewed noted that the growth of global air travel depends on a wide range of factors that are very difficult to project with much precision 50 years into the future. The IPCC report acknowledged the uncertainty involved in projecting conditions this far into the future.

In addition, the IPCC assessment assumed that future aviation growth would not be constrained by aviation or airport infrastructure.²³ According to some industry and government representatives, this assumption was unrealistic and contributed to an overstatement of aviation's future impact on the global atmosphere. Another industry representative stressed that the demand for air travel has historically paralleled economic growth as measured by the Gross Domestic Product, not by population—the indicator used by a leading environmental group in its projection.

²⁰The high-range scenario was developed by the Environmental Defense Fund—a nonprofit environmental advocacy group that has conducted research on the impact of aviation emissions on the atmosphere. The other scenarios were developed by ICAO.

²¹The IPCC measured this growth in revenue passenger-kilometers flown.

²²The IPCC report used the mid-range scenario throughout to illustrate the possible effects of aircraft on the global atmosphere.

²³The IPCC report also assumed that by 2050, improvements in fuel efficiency would be realized and optimal air traffic management would be achieved. The report further noted that if these improvements do not materialize, then fuel use and emissions will be higher.

According to this representative, the group's use of population as an indicator overestimated future demand.

A Range of Options Are Available to Reduce Aviation's Effects on the Global Atmosphere

Given that aviation currently contributes a potentially significant and growing proportion of the human additions to greenhouse gases believed to contribute to global warming, some experts we interviewed and the IPCC report identified a range of options to help limit the effects of aviation emissions as the industry grows. These options would (1) continue research to improve the scientific understanding of aviation's effects on the global atmosphere as a basis for guiding the development of aircraft and engine technology to reduce these effects, (2) promote more efficient air traffic operations through the introduction of new technologies and procedures, and (3) expand the use of regulatory and economic measures to encourage reductions in aviation emissions.

Further Research Would Help Improve Scientific Understanding and Guide Technological Development

Experts have stated that to more fully understand aviation's impact on the global atmosphere and to guide future improvements in engine and aircraft technology, additional research would be beneficial. For example, according to the IPCC, further work is required to reduce scientific and other uncertainties to better understand the options for reducing emissions and better inform decisionmakers.

Despite steady improvements in characterizing the potential effects of human activities on the atmosphere—including those of aviation—significant scientific uncertainties have been identified. According to experts and the IPCC report, further study is needed to answer the following questions:

- How do the effects of aircraft flying in the lower stratosphere compare with those of aircraft flying in the troposphere?
- Under what conditions do contrails and particles emitted from aircraft lead to the formation of cirrus clouds?
- To what extent do aerosols from aviation compare with aerosols from other sources, increase cloud formation, and change the degree to which clouds warm the earth?
- To what extent do the warming and cooling effects of methane and ozone offset each other?

Many experts believe that the scientific uncertainties associated with aviation emissions other than carbon dioxide make it difficult for

decisionmakers to identify, rank, and then target the most critical needs first. For example, one expert noted that a sound scientific footing would enable the aviation and scientific communities to address global warming in the most efficient and cost-effective manner. Furthermore, experts we interviewed cited the importance of both technological and scientific research to reduce the impact of aviation on the global atmosphere because there is currently no economically feasible alternative to the kerosene-based jet fuel used by aircraft.

NASA expects to continue its research to improve aircraft and engine technology, although its opportunities may be limited because of reductions in current and projected funding. For example, the funding for NASA's Atmospheric Effects of Aviation Project—the only U.S. government program that assesses the potential effects of aircraft emissions at cruise altitudes on climate change—is scheduled to be terminated after fiscal year 2000. In addition, funding for the Advanced Subsonic Technology and High-Speed Research programs has already come to an end; however, NASA has incorporated some elements from these programs into its new Ultra-Efficient Engine Technology program. This new program will fund engine technology research and development to reduce aircraft emissions. NASA believes that this 6-year program (running from fiscal year 2000 through fiscal year 2005) will continue efforts to reduce NO_x emissions to 70 percent below ICAO's 1996 standard. Through this program, NASA will develop technology to further reduce carbon dioxide emissions by 15 percent below today's emissions.²⁴ However, an aviation industry official noted that current aircraft engine technologies generally require a trade-off between NO_x and carbon dioxide emissions—when engines are designed to minimize NO_x emissions, they generally emit more carbon dioxide, and vice versa.

Aerodynamic improvements are expected to reduce the amount of fuel burned by aircraft. These improvements include manufacturing smoother fuselage and wing surfaces to reduce drag and using lighter and stronger materials, such as aluminum alloys, titanium components, and composite materials. Improvements in aircraft engines—anticipated through reductions in weight and applications of new engine technologies—are also expected to significantly improve fuel efficiency. However, an aviation

²⁴According to FAA officials, there is no assurance that industry will complete the development of any technology developed in NASA programs. Such development, they said, will occur in response to the marketplace or regulatory standards.

industry official pointed out that there are trade-offs between applying these new engine technologies and ensuring safety and performance.

In Europe as well as the United States, efforts are being funded to develop aircraft that will produce fewer emissions per passenger carried and, therefore, have less of an impact on the environment. The IPCC estimated that these types of improvements in aircraft and engine technology could increase fuel efficiency 20 percent between 1997 and 2015.²⁵ The IPCC also stated that fuel efficiency could increase 40 to 50 percent over current levels by 2050 if further technological improvements are realized. However, the IPCC report concluded that technological improvements alone would not fully offset the expected environmental impact of increases in aviation emissions attributable to a growing demand for air travel. As noted in the IPCC report, the amount of fuel burned by global aviation in 1990 will increase 2.7 times by 2050 as a result of increased demand for air travel, thereby increasing the aviation's industry's overall emissions.

Experts noted that in the past, NASA has made significant contributions toward reducing aircraft emissions through the development of new technologies. These improvements—in combination with those of the aviation industry—have helped aircraft to burn fuel more efficiently and, hence, reduce emissions on a per-passenger-seat basis by 70 percent over the past 40 years. In the late 1970s and early 1980s, two NASA programs, the Energy Efficient Engine Program and the Experimental Clean Combustor Program, developed engine technologies that reduce aviation emissions. According to NASA, the combustor technologies resulting from these programs reduced NO_x levels by 40 to 50 percent compared with the original first-generation annular combustor technologies.

²⁵The IPCC used forecasts developed by a group of aerospace industry experts to project future improvements in fuel efficiency.

Improved Air Traffic Operations Could Reduce Aviation Emissions

Operational improvements in such areas as communications, navigation, surveillance, and air traffic management could also lead to reductions in aircraft emissions. For example, in the United States, a range of new technologies and procedures are expected to give pilots and air traffic controllers more precise information about the location of aircraft and allow them to exchange information more efficiently. With better and more efficient communication, pilots will have more flexibility to change their routes, speed, and altitude (under certain conditions) with fewer restrictions, thus saving time and money. Better communication will also allow the FAA to improve the air traffic control system's safety and use airspace and airport resources more efficiently. According to the IPCC report, improvements in air traffic management worldwide could reduce the annual consumption of aircraft fuel by 6 to 12 percent over the next 20 years. The scenarios developed and used in the IPCC report assume that substantial enhancements to air traffic management systems will be implemented in a timely manner to substantially reduce emissions. However, our past work has noted the magnitude of effort required to implement these types of improvements globally. For example, we reported that coordinating air traffic management improvements worldwide would require the development of compatible operational concepts, technologies, and systems architectures.^{26,27} While efforts are under way in some parts of the world, much work remains to achieve worldwide coordination.

The IPCC report also observed that the environmental benefits of fuel efficiencies expected from improved air traffic operations could be offset by increases in the demand for air travel. An industry official noted that inefficiencies in the present air traffic control system currently have led to higher levels of aircraft emissions than are necessary and that improvements in communication, navigation, surveillance, and air traffic management would help reduce aircraft emissions. While improvements in air traffic management would be beneficial, our past work has identified a lack of airport surface capacity as potentially limiting the benefits of such improvements. For example, new air traffic control technologies and procedures may allow aircraft to arrive at their destinations sooner, but

²⁶A systems architecture is a blueprint/framework used to guide and constrain the development and evolution of a collection of related systems, such as the nation's air traffic control system.

²⁷*National Airspace System: FAA Has Implemented Some Free Flight Initiatives, but Challenges Remain* (GAO/RCED-98-246, Sept. 28, 1998).

limits on airport surface capacity, such as too few runways and, gates may then delay them. Limits on surface capacity can also lead to increased aircraft emissions when they cause aircraft to idle at gates and/or on taxiways or circle in the air while waiting to land.

Regulatory and Economic Measures Could Also Reduce Aviation Emissions

The IPCC report and others have reviewed regulatory and economic options to reduce aircraft emissions and their effects. These options include mandated policies, emissions trading, international charges, and voluntary agreements. ICAO's Committee on Aviation Environmental Protection is currently evaluating many of these options.²⁸ However, because of a lack of agreement among countries and the options' potential economic impact on the industry, these types of measures will require further study and debate before being implemented.

The Kyoto Protocol directs the parties to work through ICAO to address aviation's contribution to greenhouse gas emissions. Currently, the Committee on Aviation Environmental Protection, through its working groups, is studying various measures for reducing emissions from aviation. To reduce emissions, one working group is looking at technical issues, another is focusing on operational issues, and a third is looking at market-based options. These working groups are expected to report at the next regular session of the Committee on Aviation Environmental Protection in January 2001.

Emissions trading could give airlines the flexibility to reduce their own emissions or to purchase equivalent reductions from others if doing so would be less expensive. Emissions trading creates an economic incentive to employ innovative technologies and reduce emissions below the level any specific technological standard might require.²⁹ For example, each airline could be given an emissions budget for its fleet of aircraft. If one airline exceeds its budget by choosing to fly aircraft that produce higher levels of carbon dioxide or NOx, it would be required to purchase

²⁸An Air Transport Association official noted that the U.S. aviation industry has been working within this committee to assess and manage the effects of aviation on the environment.

²⁹As we have reported in the past, because of possible environmental and economic benefits, emissions trading could be part of a regulatory approach to curb carbon dioxide emissions. See *Air Pollution: Allowance Trading Offers an Opportunity to Reduce Emissions at Less Cost* (GAO/RCED-95-30, Dec. 16, 1994).

emissions credits from another airline or other regulated source that is operating below its allowable emissions budget. According to FAA, while the United States favors the use of emissions trading and voluntary measures, Europe prefers that emissions trading be one part of an entire package of options that would include charges and voluntary measures for reducing emissions. Discussions between the United States and Europe on these matters are ongoing within the Committee on Aviation Environmental Protection.

International charges on air service providers, such as landing fees based on the amounts of emissions produced and other factors, could also serve as incentives to improve operational efficiency and operate newer aircraft with lower emissions.³⁰ The practical implication of instituting such a charge is that the polluter would pay more to operate higher-emitting aircraft than to operate newer aircraft with lower emissions. According to one aviation industry expert, because the U.S. fleet tends to be older and may in some cases produce more pollution than the fleets owned by European airlines, U.S. airlines could face higher costs if charges were assessed on the basis of emissions.

Voluntary agreements within the aviation industry to meet environmental targets, such as reductions in greenhouse gases from aviation, could be used to achieve lower emissions. According to an EPA official, the aviation industry in Europe recently put forward such a proposal to reduce carbon dioxide emissions from aviation.

Agency Comments

We provided the Department of Transportation, FAA, EPA, NASA, the Air Transport Association of America, Inc., and the Environmental Defense Fund with a copy of our draft report for review and comment. The Department of Transportation and the Environmental Defense Fund did not provide comments. FAA, EPA, and NASA generally agreed with the facts presented and provided us with technical and clarifying comments

³⁰According to the IPCC report, Zurich Airport has added an emissions surcharge to its landing fee based on engine certification information. This charge is intended to provide an incentive to operators to fly their lowest-emitting aircraft into Zurich and accelerate the use of the best available technology. The IPCC report also noted that a similar emissions-related charge was applied at 10 Swedish airports in 1998. In addition, the Air Transport Association noted that the Zurich airport charge was based on the cost of taking certain measures to reduce emissions attributable to aviation operations, such as improving taxiways to decrease taxi time.

and information, which we included in the report as appropriate. EPA's and NASA's written comments appear in appendixes III and IV.

According to the Air Transport Association, the report did not establish a basis for concluding that aviation's emissions of greenhouse gases are "potentially significant." In addition, the Association said that a comparison of aviation emissions with other industrial sources should await equally thorough analyses of other industrial sectors before a comparison of the effects of aviation emissions to other sources is made. The Association also commented that our draft report did not adequately acknowledge (1) the benefits of aviation's role in the transportation system—both domestically and internationally—and (2) the progress and participation of the industry in meeting established environmental goals and advancing the scientific understanding of aviation's proper contribution to environmental challenges, such as greenhouse gas emissions. The Association provided technical and clarifying comments, which we have incorporated as appropriate.

Our conclusion that aviation's effect on the global atmosphere is potentially significant is based on our assessment of the 1999 IPCC report and our consultations with knowledgeable agency officials and other experts. We carefully considered where jet aircraft deposit the bulk of their emissions, what types of emissions they produce, and how these emissions affect the atmosphere, both by themselves and in combination with each other. We also took into account the IPCC's finding that the aviation emissions attributable to a growing demand for air travel will not be fully offset by technological improvements alone.

As for our comparisons of the amount of emissions from aviation and other sources, FAA and EPA, as well as leading experts involved in the IPCC report, concurred with our use of comparisons to establish a context for assessing aviation's relative contribution to potential changes in the global atmosphere. Furthermore, we were specifically asked to compare aviation's contribution with contributions from other sources of emissions. While we agree that data are not available to compare the relative effects of emissions from aviation and other industrial sources on the global atmosphere, data are available to compare the relative amounts of emissions from aviation and other sources—both industries and nations.

We agree that aviation provides significant benefits to the transportation system and the world economy. We added information in the background section of our report to provide this context. Our report also notes that

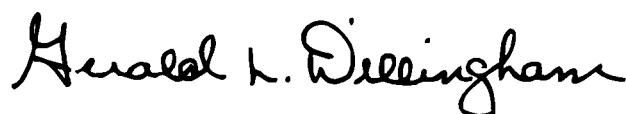
international efforts are under way to address the effects of aviation on the global atmosphere, primarily through ICAO's Committee on Aviation Environmental Protection, as specified by the Kyoto Protocol.

The complete text of the Air Transport Association's comments and our response are included as appendix V.

As arranged with your office, unless you publicly announce its contents earlier, we plan no further distribution of this report until 14 days after the date of this letter. At that time, we will provide copies of this report to interested Members of Congress; the Honorable Rodney Slater, Secretary of Transportation; the Honorable Jane Garvey, Administrator, Federal Aviation Administration; the Honorable Carol M. Browner, Administrator, Environmental Protection Agency; and the Honorable Daniel Goldin, Administrator, National Aeronautics and Space Administration.

Should you or your staff need further information, please contact me or Belva M. Martin at (202) 512-2834. Key contributors to this assignment were Sandra Cantler and Beverly Dulaney.

Sincerely yours,

A handwritten signature in black ink that reads "Gerald L. Dillingham". The signature is written in a cursive style with a large, stylized "G" and "D".

Gerald L. Dillingham
Associate Director, Transportation Issues

Objectives, Scope, and Methodology

In light of the growing demand for global air travel and the potentially increasing effects of aircraft emissions, the Ranking Democratic Member of the House Committee on Transportation and Infrastructure asked us to provide information on (1) what is currently known about aviation's contribution to global warming and how aviation emissions, both domestic and global, compare with emissions from other sources and (2) what options are available for reducing aviation's emissions.

To address the first objective, we conducted a literature search on aviation and global warming and consulted with scientific and aviation experts in the United States and Europe through briefings and interviews. Our search identified approximately 50 reports and articles published in the past 5 years. We reviewed those that were repeatedly recommended by the experts we interviewed. Through the interviews, we confirmed the adequacy of the 5-year period selected for our literature review and identified other key experts to contact. Many of the experts we interviewed recommended the 1999 report, *Aviation and the Global Atmosphere*, prepared by the Intergovernmental Panel on Climate Change (IPCC), as the most comprehensive and up-to-date source of information on the subject. Although we did not independently assess the validity of the reported research, the report was written by over 100 experts and was peer reviewed by another 150 worldwide experts on this subject and represents an attempt to reach a consensus opinion. In addition, we analyzed statistics from the Environmental Protection Agency (EPA) and Energy Information Administration to determine the quantity of emissions from various human sources, including aviation. Although we did not independently verify the accuracy and reliability of these statistics, EPA's statistics represent the official U.S. submission to the United Nations Framework Convention on Climate Change to comply with existing commitments. The Energy Information Administration is a statistical agency of the Department of Energy—mandated by the Congress to develop information independently of the Department's policy objectives—to provide data forecasts and analyses on energy and its interaction with the economy and the environment.

We also interviewed officials from the Federal Aviation Administration, EPA, the National Aeronautics and Space Administration, and the National Oceanic and Atmospheric Administration; the National Center for Atmospheric Research; airframe and engine manufacturers; nongovernmental organizations, including the Center for Clean Air Policy and the Environmental Defense Fund; aviation industry associations, including the Air Transport Association of America, Inc., the Aerospace

Industries Association, the Airports Council International-North America, and the International Air Transport Association; representatives of the European Union/European Commission; and professors from the University of California, Irvine, the University of Michigan, and the Massachusetts Institute of Technology.

For the second objective, we relied on the IPCC report, interviews with the previously cited officials, and our past work to identify the range of options for reducing aviation's impact on global warming in the future.

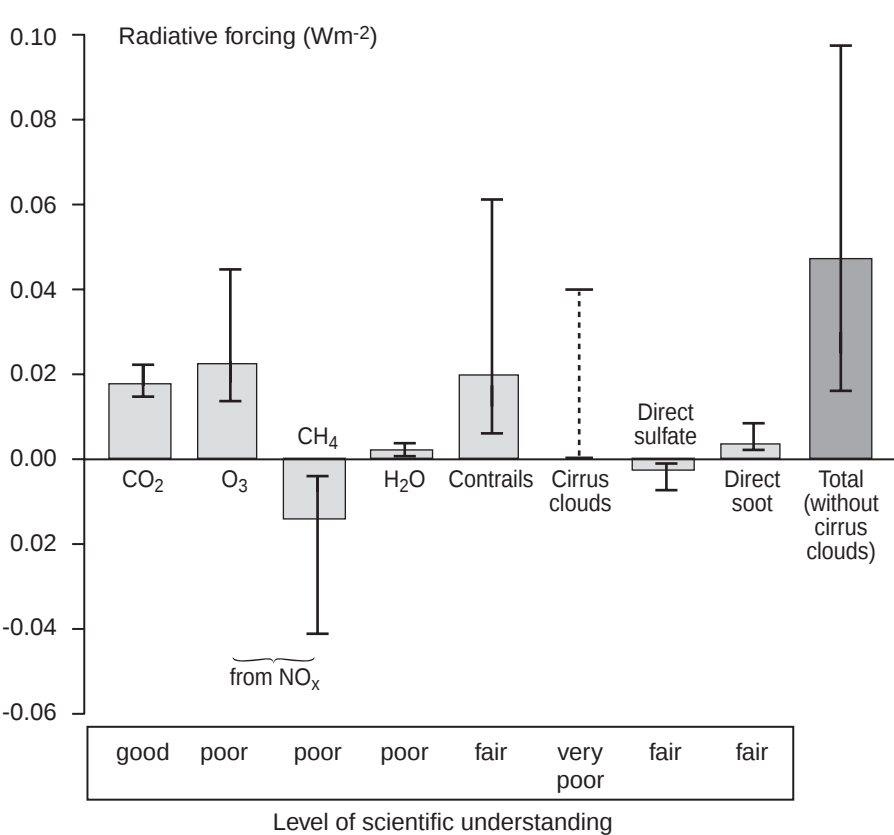
Throughout the review, the following expert reviewers helped us identify the most recent literature and reviewed our report for accuracy and balance: Dr. Daniel Albritton, Director, Aeronomy Laboratory, National Oceanic and Atmospheric Administration; Dr. Joyce Penner, Professor, Atmospheric, Oceanic and Space Sciences, University of Michigan; and Dr. Michael Prather, Professor of Earth System Science, University of California, Irvine.

We conducted our work from July 1999 through February 2000 in accordance with generally accepted government auditing standards.

Level of Scientific Understanding of Aviation's Impact on the Global Atmosphere

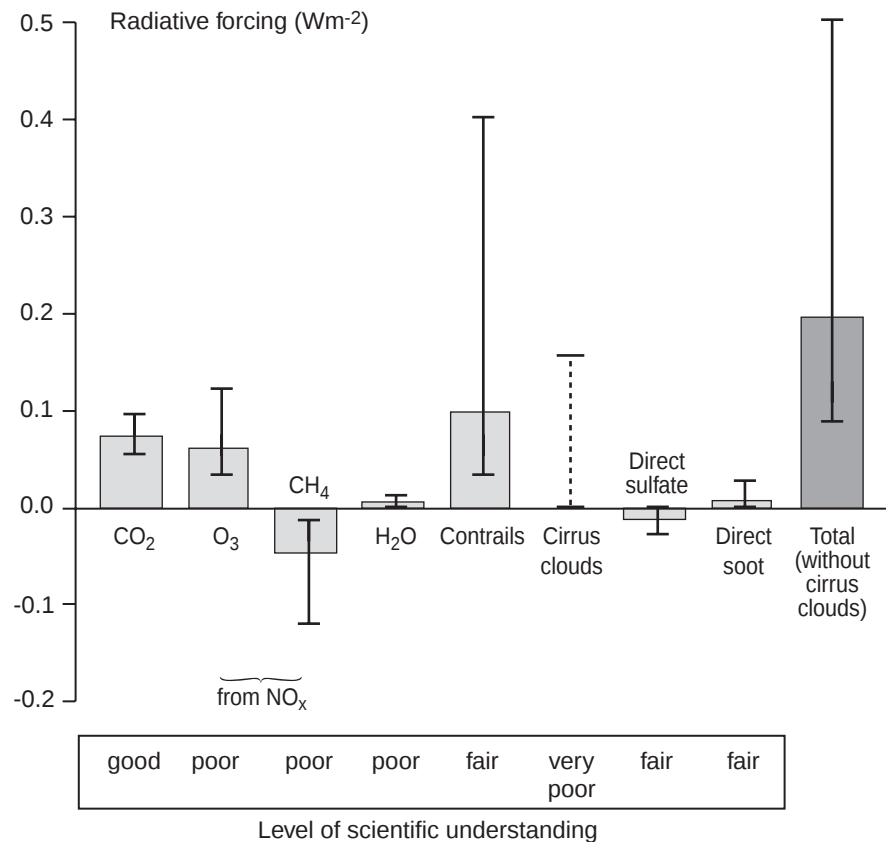
Figures 4 and 5 represent the IPCC's estimates of the globally and annually averaged radiative forcing from subsonic aircraft emissions in 1992 and 2050.

Figure 4: Radiative Forcing From Aircraft in 1992



Note: For radiative forcing, a positive value indicates warming, while a negative value represents cooling.
Source: IPCC, *Aviation and the Global Atmosphere* (1999).

Figure 5: Radiative Forcing From Aircraft in 2050



Notes:

For radiative forcing, a positive value indicates warming, while a negative value represents cooling.

The 2050 figure, from the 1999 IPCC report *Aviation and the Global Atmosphere*, was based on a 1992 scenario that was modified to reflect aviation's impact on the global atmosphere.

The scale used by the IPCC in the figure for 2050 is greater than the scale used in the figure for 1992 by about a factor of four.

Source: IPCC, *Aviation and the Global Atmosphere* (1999).

A rating—ranging from very poor to good—is assigned (below the graph) to each bar to indicate the level of scientific understanding for each component, including carbon dioxide (CO_2), ozone (O_3), methane (CH_4) water vapor (H_2O), contrails, cirrus clouds, and sulfate and soot particles. Each bar represents the “best guess” or estimate of warming, while the line associated with each bar represents the range of uncertainty for each component at the 67-percent confidence level. Specifically, this means the

Appendix II
Level of Scientific Understanding of
Aviation's Impact on the Global Atmosphere

IPCC is 67 percent confident that the true value falls within the range indicated by each line. Conversely, there is a 33-percent chance that the true value falls outside of these ranges.

Comments From the Environmental Protection Agency



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

JAN 27 2000

OFFICE OF
AIR AND RADIATION

Mr. Gerald L. Dillingham
Associate Director, Transportation Issues
U.S. General Accounting Office

Dear Mr. Dillingham:

Thank you for this opportunity to review the General Accounting Office's (GAO's) draft report "Aviation and the Environment." We believe that the report provides a very useful summary of the contribution of aviation to changes in the global environment. This report appropriately draws extensively from the recently completed international assessment, *Aviation and the Global Environment*, by the Intergovernmental Panel on Climate Change.

We believe the report would benefit substantially if the table summarizing the scientific findings taken directly from the IPCC report (pg 7) were included in its final version. While the current text discusses the content of the attached figure, including the figure itself would substantially enhance the credibility and completeness of your report. The proposed figure contains the consensus estimates of the global warming impact from subsonic aircraft and provides useful information regarding the uncertainty range associated with each emittant.

We also intend to provide more specific technical comments to your staff.

Sincerely,

A handwritten signature in black ink, appearing to read "Paul Stolman".

Paul Stolman
Director, Office of Atmospheric Programs

See comment 1.

The following are GAO's responses to the Environmental Protection Agency's letter dated January 27, 2000.

GAO Comments

1. We added the tables summarizing the consensus estimates, for 1992 and 2050, of the impact of subsonic aircraft emissions on global warming. These tables come from the 1999 IPCC report *Aviation and the Global Atmosphere*.

Comments From the National Aeronautics and Space Administration

National Aeronautics and
Space Administration
Office of the Administrator
Washington, DC 20546-0001



JAN 20 2000

Mr. Allen Li
Associate Director
Defense Acquisition Issues
National Security and
International Affairs Division
United States General Accounting Office
Washington, DC 20548

Dear Mr. Li:

I have reviewed the GAO Draft Report – Aviation and the Environment: Aviation's Effect on the Global Atmosphere Is Small but Potentially Significant and Expected to Grow.

The following comments are provided:

- Page 7: The assumption that aviation's contribution would only increase to 5% assumes a robust contribution from technology that increases fuel efficiency and NOX reductions. Achievement of these assumptions will require a significant level of technology improvement that is not currently funded.
- Page 12: The UEET program is 6 years long, not 5, running from 2000 to 2005
- Page 12: Through this program, NASA will develop technology to reduce turbine engine carbon dioxide emissions by 15% below today's emissions. NASA will not reduce the emissions, but rather provide the technology to do so.

Robert A. Pearce, who can be reached at (202) 358-4595, will contact you to set up a meeting to answer any questions you may have on our review. In response to this letter, a total of 7.5 hours were required.

Sincerely,

A handwritten signature in dark ink, appearing to read "Daniel R. Mulville", written in a cursive style.

Daniel R. Mulville
Associate Deputy Administrator

Now on p. 10

See comment 1.

Now on p. 20

See comment 2.

Now on p. 20.

See comment 1.

The following are GAO's responses to the National Aeronautics and Space Administration's (NASA) letter dated January 20, 2000.

GAO Comments

1. We added information to the report in response to NASA's comment.
2. We made the corrections to the report in response to NASA's comments.

Comments From the Air Transport Association of America, Inc.

Air Transport Association

January 21, 2000

Ms. Sandra Cantler
General Accounting Office
Transportation Issues
Resources, Community, and
Economic Development Division
441 G Street, N.W., Room 2484B
Washington, DC 20548

Dear Ms. Cantler:

Thank you for your letter dated January 7, 2000, and for the opportunity to review the proposed report of the General Accounting Office entitled "Aviation's Effect On The Global Atmosphere Is Small But Potentially Significant And Expected To Grow" (GAO/RCED-00-57). The Air Transport Association commends the GAO for its efforts to understand these complex issues, and to simplify and clarify them.

We have reviewed the report, and prepared the enclosed comments for your consideration. In response to your request that Heather Miller be listed as an expert advisor, Ms. Miller's participation was in her capacity as an ATA attorney. Appendix I to the proposed report notes that the GAO interviewed officials from the Air Transport Association, among others. Therefore, we do not believe that it would be appropriate to list any particular ATA official.

We would be pleased to discuss any questions or concerns that you may have about our comments.

Sincerely,



Patricia G. Higginbotham
Assistant General Counsel

Enclosure

Air Transport Association of America
1301 Pennsylvania Ave., NW — Suite 1100 Washington, DC 20004-1707
(202) 626-4000

Comments Of The Air Transport Association Of America, Inc.
On Proposed GAO Report Entitled
“Aviation’s Effect On The Global Atmosphere Is Small But Potentially
Significant And Expected To Grow”

The Air Transport Association¹ is grateful for the opportunity to review and comment on the proposed report prepared by the General Accounting Office entitled “Aviation’s Effect On The Global Atmosphere Is Small But Potentially Significant And Expected To Grow” (GAO/RCED-00-57).

The aviation industry has an enviable record of effectively addressing environmental challenges in this and other areas, and is prepared to continue to work with government and international agencies to address those challenges in the most cost-effective manner possible. The report addresses issues, such as the technological tradeoffs among various emissions, noise, and operational performance and the need for government mandates, that are at the heart of the debate to which the proposed report will contribute. It is important – not only to carriers, aerospace manufacturers, and financial institutions, but also to the travelling and shipping public – that the proposed report accurately reflect the industry’s efforts and at perspective.

We commend the GAO on its efforts to understand and simplify these issues. Nevertheless, the ATA is concerned that the proposed analysis does not acknowledge the progress and participation of the industry in meeting established environmental goals and advancing the scientific understanding of aviation’s proper contribution to environmental challenges, such as greenhouse gas emissions. The proposed report also assesses the effect of aircraft operations without explaining their role in the overall U.S. transportation system. Nor does it reflect the unique importance that commercial air transport has for world economic activity, which is reflected in Chapter 1 of the IPCC’s report at 17-21. For example, airline energy intensity is relatively comparable to passenger vehicle energy intensity, according to a recent report of the Department of Transportation’s Bureau of Transportation Statistics, but the safety of air transportation is dramatically better. A thorough understanding of the benefits of aviation’s role in the transportation system, both domestic and international, is important to the analysis, since the United States places a higher reliance on air service than many other countries.

The airline industry is already working with the International Civil Aviation Organization (ICAO), other international organizations, and the U.S. government to assess and manage the

¹ The Air Transport Association of America, Inc. is an association of 23 U.S. and five foreign airlines. These comments are filed on behalf of the ATA’s U.S.-flag members, who are Airborne Express, Alaska Airlines, Aloha Airlines, America West Airlines, American Airlines, American Trans Air, Atlas Air, Continental Airlines, Delta Air Lines, DHL Airways, Emery Worldwide, Evergreen International, Federal Express, Hawaiian Airlines, Midwest Express, Northwest Airlines, Polar Air Cargo, Reeve Aleutian Airways, Southwest Airlines, Trans World Airlines, United Airlines, United Parcel Service, and US Airways.

See comment 2.

See comment 1.

See comment 3.

effects of aviation on the environment. To that end, the industry has cooperated closely with the ongoing aircraft noise and emissions work of ICAO's Committee on Aviation Environmental Protection (CAEP). In addition, the airline industry, along with aircraft manufacturers' representatives, has supplied the technical assistance that the Intergovernmental Panel on Climate Change (IPCC) required to prepare its special report on the effects of aviation on the global atmosphere.

See comment 1.

The industry has an impressive environmental record, with substantial improvements to its fuel efficiency and reductions in aircraft emissions and noise. Subsonic aircraft being produced today are about 70% more fuel efficient per passenger-km than 40 years ago. Commercial air travel has also made the greatest strides in improving energy intensity. When measured by seat miles (a measure that takes account of the variation in aircraft sizes), airline energy efficiency improved 70% in just one decade, which is unequaled by any other transportation mode.² The four major components of this dramatic change were: improved load factors, increased seating capacity; aircraft type mix changes, and technical and operating efficiency improvements.³

See comment 4.

By improving fuel efficiency, the airline industry has reduced emissions. Airline industry efforts to reduce emissions started in the 1960's and have attained significant results. In 1992, the GAO reported that aircraft emissions of hydrocarbons and carbon monoxide had declined by 85% and 70%, respectively, between 1976 and 1988. When compared to the first generation of subsonic jets, today's aircraft produce less than one-quarter the total amount of hydrocarbons, carbon monoxide, and nitrogen oxide per landing and takeoff cycle.

See comment 5.

Further, the airline industry has made significant strides in the field of noise reduction over the last 25 years. Overall, today's subsonic jets, known as "Stage 3" aircraft, are 85% quieter than the first generation of jets. In the United States, the ATA acknowledged the need for progress in the reduction of aircraft noise by its aggressive support of the Airport Noise and Capacity Act (ANCA) in 1990 to mandate a phase-out of Stage 2 aircraft by the end of the decade. ANCA was based on ICAO's noise standards. ANCA also established the principle that aircraft meeting international and national environmental standards will be permitted to operate unencumbered by arbitrary local regulation for their full useful life.

See comment 6.

A key concern when dealing with the effects of aircraft on the environment is the relationship among technologies that reduce noise and those that affect gaseous emissions of aircraft, including balancing the tradeoff between these objectives and safety and performance. This balancing takes place on the international level within the CAEP. Once the CAEP strikes the

² David L. Greene, TRANSPORTATION AND ENERGY at 115-117 (Eno Transportation Foundation; 1996). Dr. Greene is a senior research staff member of Oak Ridge National Laboratory's Center for Transportation Analysis. See, also, Department of Transportation, TRANSPORTATION STATISTICS ANNUAL REPORT 1999, at 107 (reporting a 30% improvement in energy intensity between 1980 and 1996. Energy intensity is energy consumption per passenger-mile).

³ *Id.*

See comments 6
and 7.

balance, and ICAO endorses CAEP's action, aircraft operators are assured that governments worldwide will recognize national airworthiness certifications that their aircraft meet those international standards. This international treaty regime provides the legal underpinning that allows airlines and other investors in aircraft, including their institutional investors, to manufacture and invest in aircraft with confidence.

In addition, the proposed report fails to mention that every change to an aircraft engine, whether it is to address emissions or noise, affects other aspects of the engine's performance and safety. Under existing and foreseeable technology there is a tradeoff between improved fuel efficiency (and corresponding reductions of carbon dioxide emissions) and increased emissions of NO_x, an ozone precursor. Yet the report states that the "older" U.S. fleet is "more polluting." Because of the NO_x tradeoff, newer aircraft tend to emit more NO_x per payload during the landing and take-off cycle than many of the older aircraft they replace. Both of these issues are addressed thoroughly in Chapter 7 of the IPCC report.

See comment 8.

The issue of anthropogenic effects on the global climate is constantly evolving and extraordinarily technical. Scientists readily acknowledge the limits of their understanding of the science. Understanding aviation's effect on the climate system is also extremely complex, and the proposed report reflects a strong staff effort to make this difficult topic accessible to the reader.

See comment 9.

In several key respects, however, the proposed report contains technical flaws. The report states as a fact (p. 13, footnote 19) that the dual annular combustor has not received widespread acceptance due to a lack of incentives or regulatory measures. In fact, however, that technology has not received widespread acceptance for entirely different reasons. More importantly, however, these engines, which have some incremental emissions benefits, are less efficient from a fuel efficiency, and hence CO₂ emissions, perspective. Thus, their widespread use might compound, not mitigate, aviation's effect of the global climate

See comment 10.

In reviewing the proposed report, we noted the following specific concerns:

1. The proposed report states no basis for its conclusion that aviation emissions of greenhouse gases are "potentially significant," although this phrase appears in the title and throughout the proposed report. We are aware of no basis for comparing aviation's contribution to those of any other sector, since aviation was "the first thorough IPCC climate assessment of any industrial or agricultural sector. It includes all known climate forcings, many of which are important and not currently represented by indices such as GWP [global warming potential]. Comparison of aviation to other industries must await an equally thorough evaluation of the summed effects of human activities by sector that is not [currently] available."⁴ The "significance" of aviation emissions cannot be assessed in isolation, but only in comparison with other industrial sectors, including other modes of transport.

⁴ Intergovernmental Panel on Climate Change, AVIATION AND THE GLOBAL ATMOSPHERE, at 213, § 6.6.6 (1999).

Now on p. 5.

See comment 11.

Now on p. 5.

See comment 12.

Now on p. 6.

See comment 13.

Now on p. 6.

See comment 14.

Now on p. 7.

See comment 15.

2. Page 2, bullet 1. Delete the second sentence or revise the sentence to reflect the uncertainty around this statement. The IPCC report said that aircraft emissions in the upper troposphere alter the concentrations of gases there, but it did not make any conclusion about whether these changes in concentration had a greater warming effect than similar changes at the earth's surface. In fact, the report noted that some emissions tended to warm the earth, and others tended to cool the earth.

3. Page 2, bullet 2. This bullet leads the reader to infer that aviation is worse because carbon dioxide is its primary emission. In fact, carbon dioxide is the primary emission of the combustion of fossil fuels, including the production of energy, the heating and cooling of homes, and all other forms of transportation. As noted in comment #1 above, there is currently no basis for comparing industrial or agricultural sectors.

4. Page 3, bullet 3. This bullet inaccurately states the conclusion of the IPCC Special Report. The words "in aggregate, the radiative effect of these compounds could be" should replace "are believed by some to be," and the following should be added at the end "but some could produce warming while others produce cooling."

5. Page 3, last paragraph, line 3. Please add "as well as other compounds that counter this warming" to the end of the first sentence.

6. Page 4, carryover paragraph. Please add at the end of the first full sentence on page 4, "Our ability to quantify this human influence on global climate is currently limited." This more accurately reflects the findings of the IPCC's 1995 Second Assessment Report.

7. Page 4, first full paragraph, last sentence. This sentence should read, "The Parties to the Protocol recognized that the International Civil Aviation Organization has the expertise and the competence to address global climate issues attributable to aviation." Article 2.2 of the Kyoto Protocol, which reads as follows, does not "call on" ICAO for assistance, nor is it limited to international aviation:

The Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively.

8. Page 5, first and second lines. Delete "and parties to the Montreal Protocol on Substances that Deplete the Ozone Layer" and its associated footnote. The IPCC Special Report notes that the report was prepared "in collaboration with" a Montreal Protocol Panel, in response to an ICAO request.

9. Subtitle, page 6. For the reason stated in comment #1 above, delete "Potentially Significant."

Now on p. 8.

See comment 16.

Now on p. 9.

See comment 1.

Now on p. 10.

See comment 17.

Now on p. 10.

See comment 18.

Now on p. 18.

See comment 19.

Now on pp. 16-17.

See comment 20.

See comment 10.

Now on p. 11.

See comment 21.

Now on p. 13.

See comment 22.

Now on pp. 13-14.

See comment 23.

10. Page 7, carryover paragraph. The IPCC projected aviation emissions and their effects only through 2015. Beyond that, the IPCC stated, projections “are more uncertain so a range of future unconstrained emission scenarios is examined in this report.” Accordingly, the sentence that begins on line 4 with “By 2050” should be revised as follows: “By 2050, aviation’s contribution could increase to 5 percent of the total human-made radiative forcing under one mid-range scenario, but all scenarios were subject to considerable uncertainties.”

11. Page 7, carryover paragraph. The phrase “under that same scenario” should be added to the next sentence between “2050,” and “of which.”

12. Page 7, line 8. The IPCC did not make “projections” to 2050. They are scenarios based on widely varying assumptions. The sentence that begins “However, according to some aviation industry representatives” should be deleted since it suggests that the industry disagrees with IPCC’s acknowledgement, which is not the case.

13. Page 7, 2nd paragraph. First sentence delete “is” and replace with “may be” because this conclusion is speculative. Much of this paragraph is largely not derived from the IPCC report, and is apparently based on interviews with “experts.” In this regard, it is not transparent, and its objectivity is questionable. It seems more appropriate, and more objective for the GAO to rely on the current, definitive view of international experts, rather than unsubstantiated, unreviewed information. In particular, the first two sentences, which reflect opinion not part of the IPCC report should be deleted, unless they are based on peer-reviewed literature, which should be cited.

We also suggest that you replace the final two sentences with the following drawn from page 213 of the IPCC report: “On the other hand, because the IPCC Report is the first thorough IPCC climate assessment of any industrial or agricultural sector, comparison of aviation to other industries must await an equally thorough evaluation of the summed effects of human activities by sector that is not currently available.”

14. Page 8, line 6. The word “increase” should read “alter” since aircraft emissions increase some concentrations of greenhouse gases such as carbon dioxide, but reduce others, such as methane.

15. Page 9, third full paragraph, last sentence. This sentence is confusing and should be revised to read “However, increases in these emissions reduce methane — another greenhouse gas. These reductions in methane tend to cool the surface of the Earth and partially offset increases in other greenhouse gases. The IPCC noted that one effect of aircraft operations may be to decrease UV-B radiation, exposure to which is known to cause sunburn and skin cancer.”

16. Page 10, carryover paragraph. The statements regarding clouds and particles are couched in terms that are much more definitive than the IPCC was. We suggest revising the sentence on lines 2-3 by adding, at the end “although the mechanisms associated with increases in cirrus cover are not well understood and need further investigation.” This phrase appears at page 8 of the IPCC report. The effect of clouds on the global climate is one of the biggest uncertainties in

Now on pp. 18-19, 22-23.

See comment 24.

See comment 25.

See comments 1, 9, & 26.

Now on p. 23.

See comment 15.

Now on p. 24.

See comment 27.

Now on p. 24.

See comment 7.

climate science today, according to NASA, which is studying the formation of contrail-induced cirrus clouds.

17. Page 10, second paragraph, lines 5-7. Your analysis of the serious infrastructure constraints facing the industry (page 14, lines 7-11) validates our view that scenarios that assume unconstrained growth are unrealistic, and would naturally overstate aviation's impact on the global climate. We believe the text should reflect your endorsement of this statement.

18. Page 11, line 4-6. The sentence should be deleted. The ATA is extremely concerned about this statement because it devalues the IPCC's efforts and suggests that the report is unreliable or not objective. It is true that the industry, recognizing the concern about its contribution to the global climate, has taken the lead in seeking the IPCC's best advice. Further, the industry contributed considerable technical and expert resources to assist the IPCC in preparing the report. Nonetheless, the report reflects the consensus of the mainly non-industry scientific experts gathered to prepare it.

19. Page 13, footnote 19. This statement should be deleted, because the EPA official's statement is wrong, yet is stated as fact. The dual annular combustor has not received widespread acceptance for other reasons. Moreover it exacts a fuel burn penalty, which would increase CO₂ emissions, while reducing NO_x. The aviation industry has improved its fuel efficiency by more than 70% in the last 40 years, without any regulatory measures or government mandates.

20. Page 15, first bullet. The first sentence should be revised to read "Under the Kyoto Protocol, the Parties agreed to work through ICAO to address aviation's contribution to greenhouse gas emissions." for the reasons statement in Item # 6.

21. Page 15, note 23. To be accurate, this footnote should be revised to include the following: "The Zurich Airport charge was based on the cost of taking certain measures to reduce emissions attributable to aviation operations, such as improved taxiways to decrease taxi time."

22. Page 16, first line. Although the average age of the U.S. fleet may be somewhat higher than the European fleet, it is not necessarily "more polluting." Recent technological changes have actually increased the emissions of NO_x per payload in the LTO cycle, although they have improved fuel efficiency. There is no necessary connection between age of aircraft and emissions. For example, re-engined and recertificated "older" DC-8 aircraft are among the quietest and most fuel-efficient aircraft in operation today.

The following are GAO's responses to the Air Transport Association of America, Inc.'s (ATA) letter of January 21, 2000.

GAO Comments

1. Our draft report acknowledged that technological improvements by NASA and the aviation industry have helped aircraft burn fuel more efficiently and have thus reduced emissions on a per-passenger-seat basis by 70 percent over the past 40 years. We acknowledge that energy consumption per passenger-mile (energy intensity) improved 70 percent between 1980 and 1996—particularly through changes in seating capacity that increase the number of passengers or modifications to aircraft that increase the amount of cargo carried. Improved energy intensity does not necessarily enhance fuel efficiency and thereby lead to fewer emissions. As a result, we did not add the information on energy intensity because our report focuses on the effects of aviation emissions and on ways to reduce these effects.

We also added language to the report acknowledging the efforts of the aviation industry to work effectively with the U.S. government, the International Civil Aviation Organization, and other international organizations to assess and manage the effects of aviation on the environment.

2. We agree that aviation provides significant benefits to the transportation system and the world economy. For example, our draft report stated that global aviation contributed \$1,140 billion in 1994 to the world economy and this contribution was expected to increase to \$1,800 billion by 2010. We did not revise this statement in our report.

3. Our draft report stated that the industry was involved in the preparation of the IPCC report.

4. Our draft report stated that we were focusing on jet aircraft emissions in the upper atmosphere and did not address the effects of aircraft emissions on local air quality. The figures cited by ATA from our 1992 report *Air Pollution: Global Pollution From Jet Aircraft Could Increase in the Future* (GAO/RCED-92-72) referred to reductions in aircraft emissions below 3,000 feet—ground-level emissions. The effects of these emissions were outside the scope of our review.

5. While we recognize the efforts of the aviation industry to reduce aircraft noise, this report focused exclusively on aviation's effects on the global atmosphere, not on noise reduction.

6. We added language to the report noting the importance of recognizing the trade-offs between applying new engine technologies and considering safety and performance.

7. We deleted references to older aircraft as more polluting except in our discussion of regulatory and economic options to reduce aircraft emissions. Specifically, an aviation industry representative noted that the U.S. fleet tends to be older and in some cases more polluting than younger fleets owned by European airlines; therefore, U.S. airlines could face higher costs if charges were assessed on the basis of emissions.

8. We agree. Our draft report stated that except for aviation emissions of carbon dioxide whose atmospheric effects are well understood, the scientific understanding of the effects of the other aviation emissions is less certain. In addition, we included two charts from the 1999 IPCC report *Aviation and the Global Atmosphere*. These charts provide an overview of the various levels of scientific understanding of aviation's impact on the global atmosphere.

9. We deleted the reference to the dual annular combustor and, instead, referred to combustor technologies in general.

10. As stated in our draft report, we concluded that aviation's effect on the global atmosphere is potentially significant on the basis of our assessment of the IPCC report *Aviation and the Global Atmosphere*, as well as our consultations with knowledgeable agency officials and other experts. In reaching this conclusion, we carefully considered where jet aircraft deposit the bulk of their emissions, what types of emissions they produce, and how these emissions affect the atmosphere, both by themselves and in combination with each other. We also took into account the IPCC's finding that the aviation emissions attributable to a growing demand for air travel will not be fully offset by technological improvements alone.

As for our comparisons of the amounts of emissions from aviation and other sources, the Federal Aviation Administration and EPA, as well as leading experts that were involved in the IPCC report, concurred with our use of these comparisons to establish a context for assessing aviation's relative contribution to potential changes in the global atmosphere.

Furthermore, we were specifically asked to compare aviation's contribution with contributions from other sources of emissions. While we agree that data are not available to compare the relative effects of emissions from aviation and other industrial sources on the global atmosphere, data are available to compare the relative amounts of emissions from aviation and other sources—both industries and nations.

11. We disagree. The IPCC report specifically states that “aircraft emissions of NO_x are more effective at producing ozone in the upper troposphere than an equivalent amount of emissions at the surface. Also, increases in ozone in the upper troposphere are more effective at increasing radiative forcing [warming] than increases at lower altitudes.” Similarly, the IPCC report states that water vapor emissions released in the troposphere are rapidly removed by precipitation, whereas in the lower stratosphere, water vapor emissions can build up to larger concentrations that tend to warm the earth's surface. While we agree that the IPCC report found that some of these emissions tend to warm the earth and others tend to cool it, the report concluded that the net effect of these emissions is a warming of the earth's surface. See appendix II for the IPCC's overview of this net warming.

12. We clarified this point.

13. We disagree and believe that it would be misleading to imply that other compounds “counter” this warming. We made no change.

14. We agree, and our draft report stated that “The ability to accurately quantify the impact of human activity on the global climate is currently limited by a lack of understanding about how much the climate would vary without these activities.”

15. We clarified the report to indicate that the Kyoto Protocol directs parties to pursue limitation or reduction of emissions. In addition, we agree that the discussion under Article 2.2 is not limited to international aviation, but also addresses maritime emissions. However, maritime emissions are not the subject of this report.

16. We recognize that the IPCC report was prepared in collaboration with a Montreal Protocol Panel. However, the statement in our draft report referred to the requesters of the special report on aviation and the global atmosphere, not to those who prepared it. As stated in the Forward of the IPCC report, “This Special Report was prepared following a request from

ICAO and the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer.”

17. We added language to the footnote acknowledging that the IPCC scenarios are inherently uncertain.

18. We added a footnote indicating that different scenarios were used to make these estimates.

19. We modified this language to make clear that (1) the industry was concerned about the imprecision involved in estimating 50 years into the future and (2) the IPCC report agreed, as noted in our draft report, that such estimates are imprecise.

20. Much of the information used was taken from the IPCC report, and this attribution has been added. In addition, many of the experts we interviewed were directly involved in developing the IPCC report. Furthermore, the three expert reviewers of our draft report were key participants in the preparation of the IPCC report and are widely considered leading international experts.

21. We made this change in our final report.

22. Reductions in UV-B radiation are a result of NO_x-induced increases in ozone in the stratosphere. However, NO_x also increases ozone in the troposphere, and such increases tend to warm the surface of the earth. Therefore, the UV-B benefits are somewhat offset. In addition, these effects are regional, rather than global. Given the trade-offs and regional effects, we did not make the suggested change.

23. We disagree. Our characterizations of clouds and particles closely parallel those of the IPCC report. For example, our draft report said “contrails . . . may warm the earth’s surface.” The IPCC report stated that contrails “tend to warm the earth’s surface.” We changed “may” to “expected to” to match the strength of our statement with that of the IPCC. In addition, our draft report said “. . . cirrus cloud cover tends to warm the surface of the earth.” Regarding cirrus clouds, the IPCC states that “On average, an increase in cirrus cloud cover tends to warm the surface of the earth.” Our draft report stated that “. . . increases in soot tend to warm, while increases in sulfate tend to cool.” This is the same language used in the IPCC report.

24. Our report presents the views of various interested or affected groups without endorsing one particular position. Our draft report cited information from our past work on future air traffic management issues and potential constraints on airports' surface capacity to provide the reader with additional context.

25. Our intent was not to suggest that the IPCC's efforts were unreliable or not objective. However, because the reference to an environmental group's characterization of the IPCC as an industry-led effort could give this inference, we deleted this statement.

26. We deleted the footnote in the final report.

27. We revised this footnote in the final report.

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Comments From the Air Transport
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