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Report to the Chairman, Subcommittee on Aviation, Committee on Transportation and Infrastructure, House of Representatives

February 2003

AVIATION AND THE ENVIRONMENT

Strategic Framework Needed to Address Challenges Posed by Aircraft Emissions

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GAO-03-252

February 2003

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Highlights

Highlights of GAO-03-252, a report to the Chairman, Subcommittee on Aviation, House Committee on Transportation and Infrastructure

AVIATION AND THE ENVIRONMENT

Strategic Framework Needed to Address Challenges Posed by Aircraft Emissions

Why GAO Did This Study

Although noise has long been a problem around airports, the anticipated growth in demand for air travel has also raised questions about the effect of airport operations on air quality. Aviation-related emissions of nitrogen oxides, which contribute to the formation of ozone, have been of particular concern to many airport operators. A federal study at 19 airports estimated that, by 2010, aircraft emissions have the potential to significantly contribute to air pollution in the areas around these airports.

GAO agreed to review efforts in the United States and other countries to reduce emissions at airports and the effect of improvements in aircraft and engine design on emissions.

What GAO Recommends

GAO recommends that the Federal Aviation Administration (FAA) develop a strategic framework that addresses the need for information on the extent and impact of emissions, identifies reduction options, establishes goals and time frames for achieving needed reductions, and defines the roles of government and industry in developing and implementing reduction programs.

What GAO Found

Many airports have taken measures to reduce emissions, such as converting airport ground vehicles from diesel or gasoline to cleaner alternative fuels. While the actual impact of these measures is unknown, some measures (such as shifting to cleaner alternative fuels) have the potential to significantly reduce emissions, such as nitrogen oxides. In some cases—such as at Los Angeles and Dallas/Fort Worth airports—the emission reduction measures have been imposed by federal or state agencies to bring severely polluted areas into attainment with the Clean Air Act's air quality standards or to offset expected increases in emissions from airport expansion projects. Many industry and government officials that GAO contacted said that new, stricter federal air quality standards that will go into effect in 2003, combined with a boost in emissions due to an expected increase in air travel, could cause airports to be subject to more federal emission control requirements. In 1998, a group of government and industry stakeholders was established to develop a voluntary nationwide program to reduce aviation-related emissions; however, thus far, the group has not agreed to specific objectives or elements of a program.

Other countries use many of the same measures as the United States to reduce emissions at airports. Two countries have imposed landing fees based on the amount of emissions produced by aircraft. However, U.S. officials question the effectiveness of these fees.

Research and development efforts by the federal government and the aircraft industry have improved fuel efficiency and reduced many emissions from aircraft, including hydrocarbons and carbon monoxide, but have increased emissions of nitrogen oxides, which are a precursor to ozone formation. As a result, many new aircraft are emitting more nitrogen oxides than the older aircraft they are replacing. For example, GAO's analysis of aircraft emission data shows that the engines employed on the newest models of a widely used jet aircraft, while meeting current standards for nitrogen oxides emissions, average over 40 percent more nitrogen oxides during landings and takeoffs than the engines used on the older models. Technologies are available to limit nitrogen oxides emissions from some other newer aircraft models. Many state and federal officials GAO contacted said that, in the long term, nitrogen oxides emissions from aircraft will need to be reduced as part of broader emission reduction efforts in order for some areas to meet federal ozone standards.

Aircraft line up to take off

Source: Used by permission.

www.gao.gov/cgi-bin/getrpt? GAO-03-252.

To view the full report, including the scope and methodology, click on the link above. For more information, contact Gerald L Dillingham at (202) 512-3650 or DillinghamG@gao.gov.

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Abbreviations

DOT	Department of Transportation
EDMS	Emissions and Dispersion Modeling System
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
GAO	General Accounting Office
ICAO	International Civil Aviation Organization
NASA	National Aeronautics and Space Administration

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United States General Accounting Office
Washington, DC 20548

February 28, 2003

The Honorable John L. Mica
Chairman
Subcommittee on Aviation
Committee on Transportation and Infrastructure
House of Representatives

Dear Mr. Chairman:

Although aviation-related activities result in the emission of pollutants that account for only about 0.5 percent of total air pollution in the United States, these pollutants are among the most prevalent and harmful in the atmosphere and are expected to grow. The Federal Aviation Administration (FAA) expects the demand for air travel in the United States to recover from the events of September 11, 2001, and then continue a long-term trend of 3.6 percent annual growth. This expected growth has heightened concerns among some communities, environmental groups, and others that airport operations will have an increasingly detrimental effect upon the environment. Although, to date, these groups have focused primarily on the noise generated by aircraft operations, they are becoming increasingly concerned about aviation's impact on air quality. Our August 2000 report found that the operators of the nation's 50 busiest airports considered that air quality issues would become a bigger concern and challenge for them in the future than any other environmental issue.[1] Airport operators were particularly mindful of the effects on air quality of the increases in emissions due to airport growth. The emissions of most concern to many airport operators, as well as to many state and local air quality authorities, are nitrogen oxides, which are a primary contributor to the formation of ozone, a major pollutant in many metropolitan areas.

You asked us to provide information on how the aviation community is addressing current and future concerns about air quality. Specifically, you asked the following questions: (1) What efforts are being undertaken to reduce emissions from airport activities, and what are the outcomes of these efforts? (2) What additional efforts are being undertaken in other

[1]U. S. General Accounting Office, *Aviation and the Environment: Airport Operations and Future Growth Present Environmental Challenges*, GAO/RCED-00-153 (Washington, D.C.: Aug. 30, 2000).

countries to reduce aviation-related emissions? and (3) How have improvements in aircraft and engine design affected aircraft emissions?

To address these questions, we reviewed the results of environmental reviews conducted over the past 3 years at major airports located in areas (called nonattainment areas) that have not attained air quality standards required by the Clean Air Act; surveyed air quality officials from the 13 states that have major airports in nonattainment areas; and visited seven airports. To identify trends in aircraft emissions, we analyzed aircraft landing and takeoff data for the U.S. commercial aircraft fleet in 2001 using a computer model developed by FAA. In addition, we interviewed and gathered information from officials representing FAA, the Environmental Protection Agency (EPA), the National Aeronautics and Space Administration (NASA), the International Civil Aviation Organization (ICAO), airlines, aircraft manufacturers, and state and local governments. We also reviewed previous reports on aviation emission issues and available information on international efforts to reduce aviation emissions. We conducted our work from September 2001 through February 2003 in accordance with generally accepted government auditing standards. See appendix I for additional information on our objectives, scope, and methodology.

Results in Brief

Many of the nation's busiest airports and airlines have taken actions to reduce the emissions from airport activities, such as converting shuttle buses to alternative fuels, decreasing the taxiing time of aircraft, and providing electricity to aircraft parked at gates, thereby allowing aircraft to turn off their more polluting power units while crews prepare the aircraft for the next flight. Although the actual impact of these measures is unknown, some measures have the potential to significantly reduce emissions from certain sources. For example, an initiative at Dallas/Fort Worth International and Houston airports to convert ground service equipment from diesel and gasoline to electric and alternative fuel engines is expected to cut nitrogen oxides emissions from such equipment by up to 75 percent. In some cases, federal or state agencies have imposed emission reduction measures on airports located in severely polluted areas (called nonattainment areas) to help bring these areas into attainment with the air quality standards of the Clean Air Act, or to offset expected increases in emissions from airport expansion projects. In other cases, airports or airlines have voluntarily undertaken the measures. For example, the ozone pollution in the Los Angeles metropolitan area has prompted the state to require emission reductions from all sources, including airports. State and local air quality agencies have negotiated with

airlines that use five local airports, including Los Angeles International, to replace older, highly polluting ground support equipment—such as baggage handling and food service vehicles—with newer, less polluting equipment. State officials expect this action to reduce emissions from ground support equipment at the five airports by 80 percent. In addition, our analysis of the environmental reviews conducted by FAA at major commercial airports located in nonattainment areas found that most proposed airport construction projects were not required to institute any emission reduction measures to comply with emission standards. However, FAA officials told us that in the future, approval of some projects in these areas may be less likely because of several factors, including increased focus on air quality by communities that oppose airport development. In addition, in 1998, a group of government and industry stakeholders was established to develop a voluntary nationwide program to reduce aviation-related emissions however, thus far the group has not defined specific objectives or established time frames for achieving emissions reductions. In 2003, EPA plans to begin implementing stricter ambient air quality standards for ozone and other pollutants, which could make it more difficult for some localities to achieve or maintain the standards. Many in the aviation industry as well as federal and state officials believe that the new standards, combined with the boost in emissions expected from increases in air travel, could cause airports to be subject to more federal emission control requirements in the future. Currently, 26 of the 50 busiest U.S. airports are located in areas that are not attaining the current 1-hour ozone standard; however, that number could increase to 38 under the stricter 8-hour ozone standard, according to EPA estimates.

Other countries use many of the same measures to reduce emissions at airports as the United States and, in addition, two countries have imposed landing fees based on the amount of emissions produced by aircraft. Switzerland and Sweden recently implemented emission-based landing fee systems as incentives for air carriers to reduce emissions from aircraft using airports in those countries. It is too soon to determine whether the fee systems have reduced emissions at these airports, although FAA officials question the effectiveness of such fees in reducing emissions. One U.S. airport, Boston Logan International, considered emission-based landing fees in 2001, but decided they would not be a practical option for reducing emissions—particularly nitrogen oxides—because the fees would probably be too low to influence carriers' use of lower-emitting aircraft.

Research and development by NASA and aircraft and engine manufacturers have led to engine and airframe improvements that have increased fuel efficiency and yielded environmental benefits, such as reduced carbon monoxide and other emissions. However, trade-offs among several factors, including engine performance, have also led to increases in emissions of nitrogen oxides, which are a precursor to ozone formation. As a result, some of the newest aircraft are emitting more nitrogen oxides than the older, noisier, and less fuel-efficient aircraft they are replacing. For example, our estimate of emissions produced by the U.S. commercial aircraft fleet in 2001 indicates that the engines used on the newest Boeing 737 models, which are widely used for domestic flights, average over 40 percent more nitrogen oxides emissions during landings and takeoffs than the engines primarily used on older-model Boeing 737s. Technologies are being introduced that limit nitrogen oxides emissions from some other newer aircraft models. Many state and federal officials we contacted stated that, in the long term, nitrogen oxides emissions from commercial aircraft will need to be reduced as part of broader emission reduction efforts in order for some areas to meet ozone standards. Both the environmental and aviation communities have also voiced concerns that emissions from aircraft, particularly nitrogen oxides, need to be further reduced. NASA, in association with the aviation community, is working on technologies to reduce emissions of nitrogen oxides, but it is unclear if such technologies can be introduced on commercial aircraft in the foreseeable future.

To address the growing impact of aviation on air quality and the lack of progress by the stakeholders group, we recommend that FAA develop a strategic framework that examines the extent and impact of nitrogen oxides and other aviation-related emissions; considers the interrelationship among emissions and between emissions and noise; includes goals, time frames, and options for achieving emission reductions; and specifies the roles of other government agencies and the aviation industry in developing and implementing emission reduction programs. FAA, EPA, and NASA generally agreed with our findings, and FAA agreed with our recommendation.

Background

Although aviation-related activities currently account for only 0.5 percent of total air pollution in the United States, the types of pollutants emitted by these activities are among the most prevalent and harmful in the atmosphere, and are expected to grow over time. The major sources of aviation-related emissions are aircraft, which emit pollutants at ground level as well as over a range of altitudes; the equipment (such as vehicles

that transport baggage) that services them on the ground at airports; and vehicles transporting passengers to and from the airport. The amount of emissions attributable to each source varies by airport. A 1997 study of mobile source emissions at four airports found that ground access vehicles were the most significant source (accounting for 27 to 63 percent of total mobile source emissions), followed by aircraft (15 to 38 percent of the total) and ground service equipment (12 to 13 percent of the total).[2] The emissions produced by these sources include carbon monoxide; sulfur dioxide; particulate matter; toxic substances (such as benzene and formaldehyde); and nitrogen oxides and volatile organic compounds, which contribute to the formation of ozone, a major pollutant in many metropolitan areas. In addition, aircraft emit carbon dioxide and other gases that have been found to contribute to climate change due to warming. According to the United Nations' Intergovernmental Panel on Climate Change, global aircraft emissions accounted for approximately 3.5 percent of the warming generated by human activities. (The types, amounts, and impact of emissions from aviation-related sources are described in detail in appendix II.)

Although only limited research has been done on the impact of projected growth in air travel on emissions, indications are that emissions are likely to continue increasing. FAA reported in June 2001 that the number of commercial flights is expected to increase about 23 percent by 2010 and about 60 percent by 2025.[3] Each flight represents a takeoff and landing cycle during which most aircraft emissions enter the local atmosphere. In addition, an EPA study of 19 airports projected that the proportion of mobile-source emissions of nitrogen oxides attributable to aircraft in the areas adjacent to these airports will triple from a range of 0.6 to 3.6 percent in 1990 to a range of 1.9 to 10.4 percent in 2010.[4] Such projections, however, do not consider recent industry changes, such as airlines'

[2]Energy and Environmental Analysis, Inc. for Industrial Economics submitted to EPA *Analysis of Techniques to Reduce Air Emissions at Airports* (Draft Final Report) (Washington, D.C.: June 1997).

[3]Federal Aviation Administration, *FAA Long-Range Aerospace Forecasts Fiscal Years 2015, 2020 and 2025*, FAA-APO-01-3 (Washington, D.C.: June 2001).

[4]ICF Consulting Group, *Evaluation of Air Pollutant Emissions from Subsonic Commercial Jet Aircraft*, EPA420-R-99-013 (Washington, D.C.: April 1999). In this report, which was prepared for EPA, the agency acknowledged that some groups, including the air transport industry were critical of the growth projections, fleet turnover assumptions, and emissions estimates used in the report. As a result, these groups believe the report overstates the amount of emissions generated by aircraft.

increased use of smaller aircraft and the financial uncertainties in the aviation industry. A recent report by the Department of Transportation indicated that the September 11, 2001, terrorist attacks, combined with a cut-back in business travel, had a major and perhaps long-lasting impact on air traffic demand.[5]

A number of federal, state, and international agencies are involved in controlling aviation-related emissions. The Clean Air Act[6] mandates standards for mobile sources of emissions such as aircraft, ground service equipment, and automobiles. As mandated by the act, EPA promulgates emission standards for aircraft, and has chosen to adopt international emission standards for aircraft set by ICAO, which was chartered by the United Nations to regulate international aviation and includes the United States and 188 other nations. As the United States' representative to ICAO, FAA, in consultation with EPA, works with representatives from other member countries to formulate the standards. EPA and FAA work to ensure that the effective date of emissions standards permit the development and application of needed technology and give appropriate consideration to the cost of compliance, according to FAA officials. The officials also noted that EPA is responsible for consulting with FAA concerning aircraft safety and noise before promulgating emission standards. In addition to issuing aircraft emission standards, ICAO has studied aviation-related emission issues and issued guidance to its members on ways to reduce these emissions.

States can address airport emissions in plans, known as state implementation plans, [7] that they are required to submit to EPA for reducing emissions in areas that fail to meet the National Ambient Air Quality Standards set by the EPA under the Clean Air Act for common air pollutants with health and environmental effects (known as criteria pollutants).[8] Geographic areas that have levels of a criteria pollutant above

[5]Department of Transportation, Office of the Inspector General, *Airline Industry Metrics* (Washington, D.C.: January 7, 2003).

[6]42 U.S.C. 7401-7626.

[7]State implementation plans are based on analyses of emissions from all sources in the area and computer models to determine whether air quality violations will occur. If data show that air quality standards will be exceeded, the states are required to impose controls on existing emission sources to prevent this situation.

[8]The criteria pollutants are carbon monoxide, lead, nitrogen dioxide, particulate matter, ozone, and sulfur dioxide.

those allowed by the standard are called nonattainment areas. Areas that did not meet the standard for a criteria pollutant in the past but have reached attainment and met certain procedural requirements are known as maintenance areas. The options available to states for controlling pollution from airports are limited because most emissions come from mobile sources, such as automobiles, which are already regulated by EPA, and states are generally preempted from issuing regulations on aircraft emissions because of EPA's federal responsibility in this area. FAA is responsible for enforcing the emission standards and for ensuring that emissions resulting from airport construction projects under their authority comply with the National Environmental Policy Act, which requires an environmental review of such projects, and the Clean Air Act's requirement that the projects comply with state implementation plans for attaining air quality standards. (See appendix III for additional information on federal, state, and international responsibilities concerning aviation-related emissions.)

Airports and Airlines are Taking a Variety of Actions to Reduce Emissions, Although Specific Impact of These Actions Unknown

Many of the nation's busiest airports and airlines that serve them have initiated voluntary emission reduction measures, such as converting shuttle buses and other vehicles from diesel or gasoline fuels to cleaner alternative fuels. While the actual impact of these measures is unknown, some measures (such as shifting to new cleaner gas or diesel engines or alternative fuels) have the potential to significantly reduce emissions, such as nitrogen oxides, volatile organic compounds, particulate matter, and carbon monoxide. The airports and airlines have undertaken these efforts for a variety of reasons, including requirements by states imposed as part of their plans to ensure that severely polluted areas (i.e., nonattainment areas) achieve the air quality standards established by the Clean Air Act and to gain federal approval for airport construction projects. In late 2003, EPA will begin implementing stricter standards for ozone, which could make it more difficult for areas to achieve or maintain attainment status. Representatives from the aviation industry as well as federal and state officials told us that the new air quality standards, combined with the boost in emissions expected from increases in air travel, could cause airports to be subject to more emission control requirements in the future. In addition, according to FAA officials, approval of some projects in these areas may be less likely because of several factors, including increased focus on air quality by communities that oppose airport development.

Airports' and Airlines' Voluntary Actions to Reduce Emissions

Many of the nation's busiest airports, in conjunction with the air carriers that serve them, have implemented voluntary control measures to reduce emissions from major sources, including aircraft, ground support equipment, and passenger vehicles entering and exiting the airport, according to our review of FAA documents and interviews with airport and state environmental officials. Specific guidelines or regulations for airports to reduce emissions from these sources do not exist, but some airports have been proactive in developing programs and practices that reduce emissions. Although the actual impact of these measures is unknown, some initiatives have the potential to significantly reduce emissions from certain sources. For example, a number of carriers at Dallas/Fort Worth International and Houston airports have agreed to voluntarily reduce emissions associated with ground service equipment by up to 75 percent. Figure 1 provides examples of activities to reduce emissions that have been implemented at U.S. airports. Appendix V provides more information on some airports' voluntary efforts to reduce emissions.

Figure 1: Examples of Activities to Reduce Emissions

Description /general practice	Reduction of gaseous emissions of: Nitrogen oxides	Volatile organic compounds	Carbon monoxide
Aircraft (at pilots' discretion)			
Reduce operation of aircraft engines during taxi and idling time.	○	●	●
Reduce use of reversing engine thrust to slow aircraft to taxi speed after landing.	●	○	○
Limit engine thrust to a minimum by operating engines at lower power settings during takeoff.	●	○	○
Ground support equipment			
Operate ground support equipment that uses alternative fuel, such as compressed natural gas, liquefied natural gas, or petroleum gas.	●	●	●
Outfit ground support equipment with electric engines that are recharged.	●	●	●
Passenger vehicles			
Consolidate rental car facilities and airport shuttles.	●	○	●
Implement employee/tenant rideshare programs.	●	○	●
Provide public transportation to and within airport.	●	○	●
Other measures			
Use solar power and other clean fuels to generate electricity and heat.	●	●	○
Provide electricity and air-conditioning service at the gate to minimize emissions from aircraft auxiliary power units.	●	●	●

○ No effect on emissions.
● Emissions reduced.

Source: FAA and airport interviews.

Note: The information presented in this chart is not meant to include all activities for reducing emissions at airports. According to FAA, there are gaps in understanding how such activities effect various emissions, including various interrelationships among the emissions and their effects.

Most States Have Not Included Airports in Their Emission Control Strategies

Only 3 of the 13 states with major commercial airports in nonattainment areas—California, Texas, and Massachusetts—have targeted airports for emission reductions. The remaining states have not included emission reductions at airports as part of their strategies for bringing nonattainment areas into compliance with the Clean Air Act's ambient air quality standards because they have attempted to achieve sufficient reductions from other pollution sources. Officials from these states noted that EPA

has the authority to set emission standards for aircraft and nonroad vehicles, including ground support equipment at airports, which preempts the states' regulation of these sources.

California and Texas face major ozone nonattainment problems—California in the Los Angeles metropolitan area and Texas in the Dallas-Fort Worth and Houston metropolitan areas. According to air quality officials from both states, even after imposing all of the traditional emission control measures available, such as vehicle emission inspections, the three metropolitan areas still may not be able to reach attainment status for ozone by the 2010 deadline for Los Angeles and by the 2005 and 2007 deadlines for Dallas-Fort Worth and Houston, respectively. Despite potential legal challenges from airlines, both California and Texas turned to airports for additional emission control measures. Texas has negotiated an agreement with the Dallas/Fort Worth International and Houston airports and the airlines that serve them to reduce emissions attributable to ground support equipment by 90 percent. California has reached a similar agreement with the major airlines serving the five commercial airports in the Los Angeles nonattainment area to reduce emissions from ground support equipment.

California's efforts to cut ground support equipment emissions in the Los Angeles area are part of a statewide campaign to reduce airport pollution. In addition to using its limited authority under the Clean Air Act to implement airport-related emission reductions, the state has also employed a certification process provided for in federal law.[9] Under this provision, before FAA can approve a grant for any new airport, new runway, or major runway extension project, the governor must certify that the project complies with applicable air and water quality standards. California has developed criteria for determining whether a proposed airport expansion project would have an impact on the environment, including air quality. Unlike other states, California uses the criteria as a mandatory condition for project certification. If the project exceeds one of the criteria—by increasing the number of passengers, aircraft operations, or parking spaces and thereby producing an impact on the environment—the airport is required to implement emission mitigation measures in order to attain certification. Thus far, three airports—Sacramento International, San Jose International, and Ontario International—have initiated expansion projects that were required to comply with the certification

[9] 49 U.S.C. section 47106.

standards. However, in a legal opinion issued in August 2000, FAA's Office of Chief Counsel stated that California has no legal authority to impose operational limitations on airports through the certification process. According to FAA, California has not publicly responded to the opinion. A California air quality official told us that the state disagrees with the opinion and does not plan to change its certification process.

In 1999, Boston Logan International Airport began building a new runway to reduce serious flight delays. As a condition for approving the project, the state required the airport to cap emissions at 1999 levels (referred to as a "benchmark") because it has determined that the airport is a significant contributor to Boston's serious ozone problem. To stay within the limit, the airport had considered reduction strategies that include charging higher landing fees during peak operating times to reduce congestion and the resulting emissions. Now that air traffic and emission levels have fallen off since the events of September 11, 2001, the operator of the Boston airport, the Massachusetts Port Authority, believes that peak pricing and other emission reduction strategies will not be needed for several years to keep emissions below 1999 levels. The Massachusetts Port Authority, however, continues to work with airport tenants to implement voluntary emission reduction strategies. More information on states' efforts to reduce emissions appears in appendix IV.

Proposed Airport Projects Have Been Able to Conform to Current Air Quality Standards

In addition to facing control measures as part of state strategies to attain the Clean Air Act's ambient air quality standards, airports must also submit most major construction project proposals for federal environmental review, which includes an evaluation of the proposed project's impacts on air quality. The National Environmental Policy Act and the Clean Air Act require that FAA perform environmental reviews of all airport projects that involve the federal government, such as the construction of federally subsidized runways. As part of this review process, FAA must determine that emissions from projects at airports in nonattainment and maintenance areas do not adversely interfere with states' plans for the areas to reach attainment.

We examined all environmental reviews conducted by FAA at major commercial airports[10] in nonattainment areas during the 3-year period 1998

[10]Major commercial airports are the 50 busiest airports in 2001, based on air carrier operations at those airports.

to 2001. These reviews include those required by the National Environmental Policy Act as well as those required under the Clean Air Act to ensure compliance with state implementation plans for achieving ambient air quality standards. During the period, FAA performed such reviews at 24 of the 26 major commercial airports in nonattainment areas. The projects reviewed included developing runways, expanding passenger terminals and air cargo and airline support facilities, and developing roadways and intersections on airport property.

Our analysis of airport environmental review documents showed that while air quality issues are a significant consideration for airports planning major development projects, emissions have not been a major obstacle in gaining approval for projects; however, FAA is concerned that increasing emissions from operations could jeopardize the approval of future expansion projects. In 12 of the 24 cases we examined, the environmental reviews stated that the airport expansion projects would not affect air quality in the regions. The environmental reviews for 7 of these 12 projects estimated that emissions would decrease as a result of improvements in operational efficiency. For example, John F. Kennedy International Airport expected its proposed passenger terminal, air cargo, and airline support facilities expansion project to decrease the emission of nitrogen oxides by 207.2 tons per year by 2010 (about a 5-percent reduction in total airport nitrogen oxides emissions[11]) because the project was expected to decrease the amount of time aircraft take to taxi from the runway to the terminal. For 8 of the projects, significant project-related emission increases resulted from construction activities and, although the increases were temporary, the airports were required, under EPA's general conformity rules, to adopt mitigation measures to allow FAA to determine that the projects complied with state implementation plans. In only 3 cases, was a significant permanent rise in emissions expected to result from the project. Five airports —Atlanta Hartsfield, Dallas/Fort Worth International, Los Angeles International, San Jose International, and Oakland International—were required to reduce emissions from other sources in order to mitigate the effects of the increased emissions expected from either project construction or operations related to a project. Atlanta Hartsfield, for example, committed to reduce emissions associated with construction by requiring construction equipment to be operated with

[11]The reduction was calculated using total nitrogen oxides emissions from John L. Kennedy International and LaGuardia Airports for 1999.

catalytic converters that would reduce emissions and by using a massive conveyor system to haul fill material, thereby minimizing the use of trucks.

Although most recent airport construction projects in nonattainment areas met the requirements of the Clean Air Act, FAA officials noted that in the future, approval of some projects in these areas could be in jeopardy if state implementation plans did not make adequate allowances for emissions that could result from growth in aviation-related activities or include provisions for airports to offset future increases. FAA noted that approval of projects is complicated by the fact that it is often difficult to determine if a development project complies with the state implementation plan because some plans do not contain an aviation emission component, while other plans use a model or methodology to calculate aviation emissions that is incompatible with FAA's model to determine a project's compliance with air quality requirements. In addition, FAA noted that approval of some projects may be complicated by an increased focus on air quality by community groups that oppose airport projects, the insistence of EPA and/or state and local air quality agencies on mitigation measures when FAA has determined that proposed projects will reduce emissions, and the general need to better understand aviation emissions. According to FAA, approval of airport construction projects may be further complicated by differences among federal and state air quality standards, especially when state standards are more restrictive, and differences among EPA and state/local air quality agencies on the appropriate analysis and mitigation measures. Also, FAA officials have noted an increasing trend for communities to demand under the National Environmental Policy Act that FAA undertake and disclose the effects of air toxics and health effects studies. Finally, although emissions from construction activities are temporary, if they are above allowable levels, FAA is required to undertake and issue a full determination that the project/activity will conform to the state implementation plan.

Federal and State Programs for Reducing Airport Emissions

FAA, EPA, and some states have developed programs to reduce emissions from aviation-related activities and established jointly with the aviation industry a process that has tried to reach a voluntary consensus on how to further reduce emissions. For example, as part of its Inherently Low-Emission Airport Vehicle Pilot Program, required by Congress in 2000,[12]

[12] 49 U.S.C. section 47136.

FAA awarded federal grants of up to $2 million to each of 10 airports[13] for alternative fuel vehicles and infrastructure. FAA is using the program to evaluate the vehicles' reliability, performance, and cost-effectiveness in the airport environment. FAA initially anticipated that the program would reduce emissions by 22,584 tons of ozone, 314,840 tons of carbon monoxide, 384 tons of particulates, and 924 tons of sulfur dioxide during the projected lifetime of the airport equipment. To achieve this reduction, FAA expected the airports to purchase about 1,600 pieces of alternative fuel ground support equipment and 600 alternative fuel ground access vehicles, such as airport cars, buses, and shuttles. As of October 2002, FAA reported a slower-than-expected start-up of the program, with only five airports (Baltimore-Washington International, Dallas/Forth Worth International, Baton Rouge Metropolitan, Sacramento International, and Denver International) making notable progress on the program. According to FAA, the effects of the events of September 11, 2001, have caused unforeseen delays and acquisition deferrals for many low-emission vehicle projects, particularly those that rely on airline financing to convert ground support equipment to alternative fuels.

Although FAA plans to provide $17.3 million for the Inherently Low-Emission Airport Vehicle Pilot Program, airports and air carriers expressed the need for more federal funding to reduce emissions. Some airports have said that they would like flexibility in how the Airport Improvement Program[14] or passenger facility charge[15] funds can be used to mitigate or offset emissions from expansion projects. For instance, Sacramento Airport officials stated that they would like the city's light rail system to be connected to the airport to reduce emissions from ground access vehicles. However, Airport Improvement Program or passenger facility charge funds cannot be used for emission mitigation projects

[13]The 10 airports are Atlanta Hartsfield, Baltimore Washington International, Baton Rouge Metropolitan, Denver International, Dallas/Fort Worth International, New York John F. Kennedy International, New York LaGuardia, Chicago O'Hare International, San Francisco International, and Sacramento International.

[14]FAA's Airport Improvement Program provides grants to airports for capital development. FAA allocates most grants on the basis of a legislated formula tied to the number of passengers an airport enplanes and categories earmarked for specific types of airports and projects.

[15]Most airports are able to charge passengers a boarding fee, called a passenger facility charge, to help pay for their capital development projects. The program is managed by FAA, which approves an airport's application to participate and the specific projects to be funded.

located outside airport property. According to FAA, DOT's Congestion Mitigation and Air Quality grant program can be used to finance emission mitigation projects located outside of airport property.

Some states also have emission reduction assistance programs that are available to airports. The California Environmental Protection Agency developed the Carl Moyer Program, which is an incentive-based program that covers the incremental cost of purchasing airport vehicles with cleaner engines, including ground support equipment at airports. The program taps into available new environmental technologies to help the state advance clean air goals. It provides funds to private companies or public agencies to offset the incremental cost of purchasing the cleaner engines. The Texas Natural Resource Conservation Commission also established incentive funds for emission reduction efforts, similar to California's program. As in California, the funds are not specifically designated for emission reductions at airports, but air carriers that are not participating in the agreement with the Commission to voluntarily reduce ground support equipment emissions can receive grants to convert their ground support equipment. Airlines that are part of the voluntary agreement would not be eligible for the incentive funds.

Some airport operators we spoke with would like EPA to set up a process in which airports could obtain "credit" for the amount of emissions reduced by their voluntary efforts; the credits can be "banked" by the airport to use at a future date to offset expected increases in emissions or they can be sold to other nonairport entities in the region that are required to offset emissions. The airport operators also indicated that having such a program encourages airport sponsors to undertake efforts to reduce emissions. Such an emission credit program is available in Washington State. Airports there can implement emission reduction efforts and obtain emission credits, which they can save and use to offset increased emissions from future expansion projects. Thus far, such a system has been adopted at one location, Seattle–Tacoma International Airport, which worked with the local clean air agency to establish a credit program for voluntary emission reduction actions. If airports are not allowed to save emission credits, any voluntary reductions will lower their emission baseline, which is used to calculate the impact of future emissions, and limit their options for any emission reductions required to obtain approval

for future projects.[16] Because of this situation, some airport officials told us that they have waited to initiate emission reduction efforts until the efforts are needed to gain approval for an expansion project. EPA encourages airports to contact their state and local air quality agencies and negotiate emission credit agreements, as was done by Seattle-Tacoma International Airport. However, according to FAA officials, this localized case-by-case approach to issuing emission credit is inefficient. Instead, FAA supports a consistent national approach that it believes would lessen the burden on airports to obtain emission credits from their respective states.

In 1998, FAA and EPA established a process—known as the stakeholders group—which includes representatives from state environmental agencies, airports, air carriers, and the aerospace industry to discuss voluntary efforts to lower nitrogen oxides and other emissions. They established the process because federal and industry officials told us that the current approach to reducing emissions—uncoordinated efforts by individual airports and states—was inefficient and possibly ineffective from a nationwide perspective. For example, some federal officials believe the current approach encourages airlines to move their more polluting equipment to airports that do not require cleaner vehicles, and the aviation industry is concerned about the impact that differing state requirements might have on their operations. According to EPA, another reason for establishing the process was concerns by EPA, state environmental agencies, and environmental groups about international emissions standards, particularly standards for nitrogen oxides.

The stakeholders group decided to focus on achieving lower aircraft emissions through a voluntary program because this strategy offered the potential for achieving desired goals with less effort and time than a regulatory approach. Initially, the group's discussions focused on emission reduction retrofit kits, which could be applied to some existing aircraft engines, but this was found to not be technically feasible. However, as the process evolved, the stakeholders expanded the focus to evaluating various emission reduction strategies for aircraft and ground support equipment. According to participants, the group is currently working to

[16]For example, if an airport produces 100 tons of nitrogen oxides per year and then voluntarily initiates a project that reduces the amount by 10 tons, the baseline becomes 90 tons. If an expansion project then results in a 10-ton yearly increase in nitrogen oxides, the airport might have to initiate new mitigation measures that will compensate for the increase.

establish a national voluntary agreement for reducing ground service equipment emissions in the nearer term, similar to the agreement in California. In the longer term, the group is considering reductions in aircraft emissions through an approach known as "environmental design space" that recognizes the need to balance such reductions with other competing goals such as noise reduction, while assuring safety and reliability. FAA also noted that airport operators used the stakeholders group to highlight the need for more guidance on the process for ensuring that federal actions, such as the construction of new runways, conform to the appropriate state implementation plans. FAA and EPA issued guidance on the process in September 2002. The group had also commissioned a study to establish a baseline of aviation-related emissions and another study of options for reducing them. However, the study will not be completed because of resource constraints, according to participants.

FAA noted that the progress of the stakeholders group has been impeded by the impact of the events of September 11, 2001, on the airlines and the complex nature of addressing all stakeholders' viewpoints to achieve consensus on a framework that can be applied nationally. The activities of the group were suspended after September 11, but resumed in May 2002. According to one member of the group, many participants have been frustrated by the group's slow progress, but they hope to define a nationwide program to reduce emissions from ground service equipment in 2003 and continue discussion of aircraft emission reduction options. However, the group has not defined specific objectives or established time frames for achieving its goal of reducing aviation-related emissions. Furthermore, the group's activities may be limited by the financial situation of participating air carriers.

New Air Quality Standards Will Pose a Challenge to Some States and Airports

In late 2003, EPA plans to begin implementing a more stringent standard for ozone emissions, which could require more sources, including airports, to tighten controls on nitrogen oxides and some types of volatile organic compound emissions, which contribute to ozone formation. The new standard calls for concentrations of ozone not to exceed .08 parts per million over 8-hour blocks of time; the current standard requires concentrations not to exceed .12 parts per million over 1-hour blocks of time. Some state air quality officials that we spoke to believe that the continued growth of aviation-related ozone precursor emissions, coupled with such emissions from other sources, may affect their ability to meet to the new standard.

The implementation of the 8-hour standard for ozone could have significant implications for airports. Currently, 26 major commercial airports are located in nonattainment areas for ozone. EPA has yet to designate and classify which areas will not be in attainment with the 8-hour standard. However, the agency estimates that under the 8-hour standard, areas containing 12 additional airports could be designated as nonattainment areas. Airports in these areas could be constrained in their ability to initiate development projects if they did not comply with the state implementation plans. EPA, however, believes that the new 8-hour standard provides an opportunity for the airports and the states that have not addressed airport emissions in their state implementation plans to identify airport emission growth rates when new plans are developed under the 8-hour standard.[17]

Among the 13 state air quality officials we surveyed, 5 expect that aviation emissions will somewhat or moderately hinder their state's ability to demonstrate compliance with EPA's new 8-hour ozone emission standard, and 3 stated that aviation emissions will greatly hinder their ability to comply.[18] Some of these officials also said they are uncertain how their state will meet the new standards. Because the new 8-hour standard is more stringent, the states will need to develop more rigorous and innovative control measures for all sources and may have to rely on the federal government to reduce emissions from sources over which the state does not have jurisdiction, such as aircraft engines.

Two Countries Have Introduced Emission-Based Fees

Other countries use many of the same measures to reduce emissions at airports as the United States and, in addition, two countries have imposed landing fees based on the amount of nitrogen oxides emissions produced by aircraft. Emission-based landing fees and other market-based methods are currently being studied by ICAO and the former have been implemented in Switzerland and Sweden.[19] Emission-based landing fees,

[17]In September 2002, FAA and EPA issued guidance for airports developing early emissions reduction programs.

[18]The 13 states encompass all 26 of the top 50 busiest commercial airports located in areas designated as not in attainment for ozone.

[19]Market-based options are rewards or inducements to reduce emissions. They can be in the form of charges, emission credit-trading regimes, and voluntary measures. According to ICAO, market-based measures are policy tools that are designed to achieve environmental goals at a lower cost and in a more flexible manner than traditional emission reduction measures.

although considered for Boston Logan International Airport, have not been implemented at any U.S. airports and many in the U.S. aviation community question their effectiveness.

ICAO established a working group to identify and evaluate the potential role of market-based options, including emission charges, fuel taxes, and emission-trading regimes,[20] in reducing aviation-related emissions. Thus far, the working group has concentrated on carbon dioxide emissions and has concluded that the aviation sector's participation in an emission-trading system would be a cost-effective measure to reduce carbon dioxide in the long term. The ICAO Assembly, the organization's highest body, has endorsed the development of an open emission-trading system for international aviation and has instructed its Committee on Aviation Environmental Protection to develop guidelines for open emission trading. The ICAO committee has also been studying emission charges or taxes as well as evaluating voluntary programs to reduce emissions. ICAO's current policy, adopted in 1996, recommends that emission-based fees be in the form of charges rather than taxes and that the funds collected should be applied to mitigating the impact of aircraft engine emissions.

Switzerland was the first country to implement a market-based system for reducing aviation-related nitrogen oxides and volatile organic compound emissions. In 1995, the Swiss federal government enacted legislation that allowed airports to impose emission charges on aircraft. In September 1997, the Zurich airport used this authority to establish emission-based landing fees as an incentive for air carriers to reduce emissions from aircraft using the airport. The use of emission-based landing fees has expanded to other airports in Switzerland and Sweden. The Geneva, Switzerland, airport implemented an emission-based landing fee similar to the fee scheme used in the Zurich airport in November 1998. Several Swedish airports also implemented emission fees after the Swedish Civil Aviation Administration approved such charges in January 1998. Similar to the system at Zurich airport, the Swedish airports reduced the landing

[20]Emissions trading is a market based approach to reducing emissions. As practiced in the United States, a "cap" or limit is set on the amount of emissions allowed from regulated sources, such as power plants. The cap is set lower than historical emissions to cause reductions. Sources are then given an allowance, which authorizes them to emit a fixed amount of a pollutant. Sources whose emissions are lower than their allowance, can sell the remainder of their allowance on the open market to sources that have exceeded their allowance.

charges so that income from emission charges is not considered an additional source of revenue.

The establishment of emission-based landing fees in Switzerland and Sweden has affected the operations of airlines with frequent flights to airports in these countries. According to a representative of a jet engine manufacturer, a Swiss airline purchased a number of new aircraft equipped with engines designed to emit lower amounts of nitrogen oxides. The representative said that the airline wanted the engines in order to reduce its landing fees at Swiss airports. However, the airline filed for bankruptcy in 2001 and has ceased operations. Only a few other airlines have expressed interest in equipping their new aircraft with engines that emit less nitrogen oxides because they are more expensive and less fuel-efficient and have higher operating costs. As of December 2002, no other airlines had purchased such engines.

No conclusive studies on the effectiveness of these emission-based landing fees have been completed. According to the Zurich Airport Authority, results of the emission-based landing fee can be shown only in the long term, making it difficult to quantify whether emissions such as nitrogen oxides or volatile organic compounds have been reduced. (FAA officials stated that the effects of emission-based fees can be estimated using existing models. For example, a 2001 ICAO working paper on market-based options for reducing carbon dioxide emissions found that enroute emissions charges would be insufficient to meet reduction targets.) Nevertheless, an aviation expert said that the emission-based landing fees have caused airlines to begin considering the cost of nitrogen oxides and volatile organic compound emissions as part of their business decisions.

Emission-based landing fees have not been introduced at any U.S. airports. Boston Logan International Airport considered implementing such fees to reduce emissions, but a 2001 study commissioned by the Massachusetts Port Authority, which operates the airport, determined them to be ineffective.[21] The study found that emission-based landing fees would be a small portion of commercial air carriers' operating expenses and would be unlikely to affect their operational, purchasing, or leasing behavior substantially enough for them to consider using lower nitrogen-oxides-emitting aircraft and engines. Thus, the study concluded, the emission-

[21]Massachusetts Port Authority, *Air Quality Initiative for Boston Logan International Airport* (March 2001).

based landing fees would not significantly induce commercial airlines to use aircraft engines emitting lower levels of nitrogen oxides.

Improvements in Aircraft and Engine Design Have Reduced Many Aircraft Emissions, but Nitrogen Oxides Emissions are Increasing

Although research and development efforts by NASA and aircraft and engine manufacturers have led to engine and airframe improvements that have increased fuel efficiency and lowered carbon dioxide and hydrocarbon emissions, trade-offs among several factors, including engine performance, have also resulted in increased nitrogen oxides emissions. Our analysis of data on aircraft emissions during landings and takeoffs indicates that the newest generation of aircraft engines, while meeting international standards, can produce considerably more nitrogen oxides emissions than the older versions they are replacing. Engine options for some aircraft are now being introduced that reduce nitrogen oxides emissions. Additionally, NASA has ongoing research into technologies that could reduce nitrogen oxides emissions from jet engines to well below current standards. However, aviation industry representatives are unsure whether the technologies will ever be developed to the point where they can be incorporated into future production engines because of uncertainties about funding and other factors. Given the long lifespan of aircraft, even if the technologies are developed, it could be decades before enough airplanes are replaced to have a measurable effect on reducing nitrogen oxides. As a result, both the environmental and aviation communities have expressed concerns that emissions from aircraft, particularly nitrogen oxides, need to be further reduced.

Improvements in Aircraft and Engines Have Reduced Fuel Consumption and Most Emissions

Improvements in jet engine design have led to increases in fuel efficiency and reductions in most emissions, particularly emissions from aircraft flying at cruise altitudes. Historically, the improvements in fuel consumption for new aircraft designs have averaged about 1 percent per year. The aviation industry and NASA, which are developing fuel reduction technologies, expect this rate to continue for the next two decades. Air carriers' desire to control fuel costs provided the impetus for these efforts. (Appendix VI provides a brief overview of fuel reduction technologies.)

According to aircraft design experts, fuel consumption is the single biggest factor affecting the amount of most aircraft emissions. Table 1 shows the amount of emissions produced by a typical aircraft turbine engine during cruising operations for each 1,000 grams of fuel burned.

Table 1: Aircraft Turbine Engine Emission Amounts during Cruising Per 1000 Grams of Fuel Burned

Type of emissions	Amount of emissions (in grams)
Carbon dioxide	3,200
Water	1,200
Nitrogen oxides (as nitrogen dioxide)	15
Carbon monoxide	1
Sulfur oxides	1
Hydrocarbons (as methane)	0.20
Soot (as carbon)	0.02

Source: National Research Council.

Note: *For Greener Skies, Reducing Environmental Impacts of Aviation* (Washington, D.C.: National Academy Press, 2002).

According to aviation experts, new aircraft designs are reducing carbon dioxide emissions by about 1 percent per year—the same rate at which fuel consumption is being reduced. ICAO expects this carbon dioxide and fuel reduction trend to continue for the next 20 years. Carbon monoxide and hydrocarbon cruise emissions are declining even faster than the fuel reduction rates. These emissions, which are formed when a portion of the fuel is only partially combusted, are much easier to minimize with the hotter engine temperatures of the new more fuel-efficient engine designs.

New Aircraft Designs Produce Significantly More Nitrogen Oxides during Landings and Takeoffs

A byproduct of the improvements in jet engine design has been an increase in nitrogen oxides emissions during landings and takeoffs and while cruising, according to aviation industry experts. The new engine designs are capable of operating at higher temperatures and producing more power with greater fuel efficiency and lower carbon monoxide emissions. However, as engine-operating temperatures increase so do nitrogen oxides emissions. This phenomenon is most pronounced during landings and takeoffs, when engine power settings are at their highest. It is during the landing/takeoff cycle that nitrogen oxides emissions have the biggest impact on local air quality.

Our analysis of aircraft landing/takeoff emissions shows that newer aircraft produce considerably more nitrogen oxides than older models. We identified examples of aircraft models and engines introduced in the last 5 years and compared their emissions with emissions from older aircraft

they might replace.[22] We found, for example, that although the newer Boeing 737 series aircraft are more fuel-efficient, are capable of flying longer distances (or with more weight), emit less carbon monoxide and hydrocarbons, and produce less takeoff noise than their predecessors, they also produce 47 percent more nitrogen oxides during landing/takeoff (see table 2).[23]

Table 2: Comparison of Emissions during Landing/Takeoff for Older and the Newest Model Boeing 737s

	Average emission (in pounds) per landing/takeoff		
Emission	**Older Boeing 737**	**Newest Boeing 737**	**Change**
Nitrogen oxides	12.1	17.8	47% increase
Carbon monoxide	16.8	10.7	37% decrease
Hydrocarbons	1.2	1.1	10% decrease

Source: GAO.

Note: Landing and takeoff data for U.S. aircraft in 2001 obtained from AvSoft; emissions calculated using FAA's Emissions and Dispersion Modeling System, version 4.01. See appendix VII for additional information on our emission calculations and Boeing 737 models and engines.

Significantly higher emissions of nitrogen oxides during landing/takeoff for the aircraft introduced in the last 5 years also occur in the largest aircraft. For example, the Boeing 777, the newest of the large jets, emits significantly more nitrogen oxides than comparable older aircraft. Table 3 compares a passenger model Boeing 747-400 with the Boeing 777 model and engines that it is most comparable to in seating capacity and range. Even before we adjusted for the greater seating capacity of the larger Boeing 747-400, we found that the most comparable Boeing 777—the 200ER model—produces 34 percent more nitrogen oxides emissions, even

[22]To the extent possible, we compared aircraft that can be used interchangeably to fulfill the same mission (same number of passengers, same range). In instances where aircraft fly the same routes but have different seating capacity, we made comparisons on a per seat basis. The most straightforward comparison of newest versus older aircraft emissions involves the various Boeing 737 models. This family of medium-sized jets made 22.6 percent of all landings and takeoffs in the 2001 U.S. aircraft fleet. Furthermore, all models in this family have been updated in the last 5 years with improved airframes and engines.

[23]The U.S. 2001 commercial fleet included 988 older Boeing 737s. They accounted for 17.6 percent of this fleet's landings and takeoffs and 13.4 percent of this fleet's nitrogen oxides emissions during landing and takeoffs. The U.S. 2001 commercial fleet included 449 newer Boeing 737s. They accounted for 5.0 percent of this fleet's landings and takeoffs and 5.5 percent of this fleet's nitrogen oxides emissions during landings and takeoffs.

though ICAO data shows that the Boeing 777 is quieter and more fuel-efficient than the older aircraft it is replacing. For example, on a per seat basis, the Boeing 777 can be as much as 30 percent more fuel-efficient than older model Boeing 747s.

Table 3: Comparison of Boeing 747 and 777 Emissions on a Per Aircraft Basis

	Emission (in pounds) per aircraft during landing/takeoff		
Emission	**Boeing 747-400**	**Boeing B777-200ER**	**Change**
Nitrogen oxides	103.5	124.2	20 percent increase
Carbon monoxide	47.7	30.4	36 percent decrease
Hydrocarbons	4.1	2.4	41 percent decrease

Source: GAO.

Notes: Landing and takeoff data for U.S. aircraft in 2001 obtained from AvSoft; emissions calculated using FAA's Emissions and Dispersion Modeling System, version 4.01. See appendix VII for additional information on our emission calculations and details about these aircraft and their contribution to the 2001 U.S. commercial fleet totals.

The Boeing B777-200ER data is the weighted average (based on 2001 landings and takeoffs) for three different engines. The nitrogen oxides and other emission characteristics of these engines vary significantly.

As shown in table 4, the percentage increase in nitrogen oxides during landing/takeoff is 57 percent when the two aircraft are compared on a per seat basis (the amount of emissions divided by the number of seats on the aircraft).

Table 4: Comparison of Boeing 747 and 777 Emissions on a Per Seat Basis

	Emission (in pounds) per seat during landing/takeoff		
Emission	**Boeing 747-400**	**Boeing B777-200ER**	**Change**
Nitrogen oxides	0.287	0.451	57 percent increase
Carbon monoxide	0.132	0.110	16 percent decrease
Hydrocarbons	0.011	0.009	20 percent decrease

Source: GAO.

Note: Landing and takeoff data for U.S. aircraft in 2001 obtained from AvSoft; emissions calculated using FAA's Emissions and Dispersion Modeling System, version 4.01. GAO analysis of AvSoft 2001 landing and takeoff data for U.S. aircraft.

EPA and FAA regulate nitrogen oxides emissions and other emissions for U.S. commercial aircraft by requiring engine designs to meet ICAO standards for these emissions. Prior to production, all new engine designs are tested to determine the amount of nitrogen oxides and other emission

characteristics.[24] Only engines that meet the standards are certified for production. ICAO standards for nitrogen oxides were first adopted in 1981 and more stringent standards were adopted in 1993 (20 percent more stringent, effective 1996) and again in 1998 (16 percent more stringent, effective 2004). ICAO working groups are assessing whether or not the standards for nitrogen oxides emissions should be made more stringent than the standards that will take effect in 2004. Options being considered could make the standards between 5 percent and 30 percent more stringent between 2008 and 2012.

Under ICAO standards, newly designed engines and modified versions of older designs are allowed to produce significantly more nitrogen oxides than their predecessors. This is because the ICAO standards recognize that nitrogen oxides emissions are a function of engine power capability and operating pressure. Therefore, the standards allow for higher nitrogen oxides emissions for engines that (1) operate at higher-pressure ratios, which increase their fuel efficiency and (2) produce more power. For example, the most common updated Boeing 737-700 aircraft model and engine produces 41 percent more nitrogen oxides during landing/takeoff than the most common older version it is replacing (see table 5). Both engines will meet the new ICAO standard, which will go into effect in 2004 (the old engine betters the standard by about 15 percent, the new one by about 10 percent). A lower nitrogen oxides producing engine is available for the Boeing 737-700. This engine produces 18.5 percent more nitrogen oxides than the older Boeing 737-700 that it is most comparable to in power and versatility.[25] However, this engine is less common in the fleet that then the more powerful one that offers more aircraft versatility. The database we use shows that in the U.S. fleet there were 8 Boeing 737-700s with the lower nitrogen oxides emitting engines and 118 with the more powerful engines.

[24]Almost all that is known about the emission characteristics of a particular engine comes from these certification tests, which cover four modes of the landing/takeoff cycle (taxi in/taxi out, takeoff, climb out, and approach). Landing/takeoff emissions are derived from computer models that combine the engine certification emission data with characteristics of specific aircraft.

[25]The ICAO Engine Exhaust Emissions Data Bank lists the power of the CFM56 3B-1 engine (used on the Boeing 737-700) at 89.4 kiloNewtons. The CFM56 7B-20 (used on the Boeing 737-700) is rated at 91.6 kiloNewtons.

Table 5: Comparison of Power, Engine Operating Pressures, and Nitrogen Oxides Emissions for Two Models of Boeing 737s

Characteristic	Older model B737-300	Newest model B737-700
Engine variant	CFM56 3B-1	CFM56 7B-22
Power (thrust) per engine	89 kiloNewtons	101 kiloNewtons
Engine operating pressure ratio	22.4	24.41
Landing/takeoff nitrogen oxides emissions	10.72 pounds	15.08 pounds

Source: GAO.

Note: Landing and takeoff data for U.S. aircraft in 2001 obtained from AvSoft; emissions calculated using FAA's Emissions and Dispersion Modeling System, version 4.01. See appendix VII for additional information on our calculations and details about these aircraft.

There is an ongoing debate between the aviation and environmental communities over the best method for developing nitrogen oxides certification standards. Some in the aviation community want to maintain the current system under which the standards are made more stringent only when the engine manufacturers have produced engines that meet the new standards and new standards only apply to newly certified engines.[26] (An industry official identified only two older types of engines that would not meet the more stringent 2004 nitrogen oxides standards.) Officials for the aviation industry said that it would be inadvisable to force more aggressive nitrogen oxides standards because new engine development programs are already complex and have many business and schedule risks. These officials added that the environmental regulatory process lacks cost-benefits data to defend a more aggressive approach that could result in extreme financial harm for engine and aircraft manufacturers if the approach delayed a new program. Further, some believe that if reductions in nitrogen oxides were to become a higher priority, it would be better to have market-based incentives that reward lower nitrogen oxides emissions than have aggressive and rigid pass/fail regulatory barriers.

Moreover, some federal, state, and local environmental officials believe more incentives are needed to reduce aircraft nitrogen oxides emissions beyond the ICAO certification standards that are to take effect in 2004. They say that the current system gives little value to reducing nitrogen oxides in the many trade-offs among emissions, fuel-consumption, and

[26]According to FAA, this approach has produced an aircraft fleet that is about 65 percent more fuel efficient than in 1970 and aircraft engines with a high safety record.

other factors made during engine design. They reason that if there were more incentives to reduce nitrogen oxides emissions beyond the certification requirements, these incentives would accelerate innovations that minimize degradations in other engine performance characteristics such as fuel efficiency.

While NASA and engine manufacturers have made continuous improvements for decades in technologies that have improved fuel efficiency, decreased noise, and decreased all emissions including nitrogen oxides, the design of the newest generation of engines has resulted in trade-offs that favor fuel efficiency and increase nitrogen oxides. Two engine manufacturers have responded to this problem by developing options for several new engines that reduce nitrogen oxides. (General Electric has developed a "dual annular combustor" technology for one of its CFM56 engines and Pratt Whitney has developed a "Technology for Affordable Low NOx" [TALON] for some of its engines. This TALON technology is being used on some aircraft in the U.S. fleet.) According to NASA, about 100 engines using one of these technology options are currently in service on passenger and cargo aircraft. According to industry officials, knowledge gained from developing these options is contributing to ongoing nitrogen oxides reduction research.

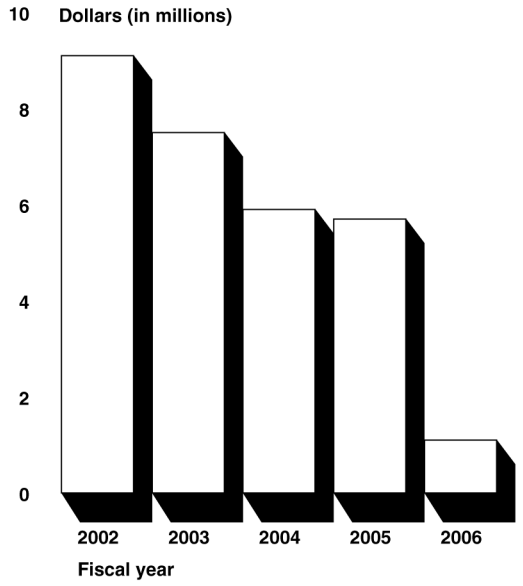
Potential Success of Efforts to Reduce Aircraft Nitrogen Oxides Emissions Uncertain

NASA, in association with jet engine manufacturers and the academic community, is working on several technologies to reduce nitrogen oxides emissions, although it is unclear if they can be introduced on commercial aircraft in the foreseeable future. If successfully developed and implemented, these technologies could significantly lower the emission of nitrogen oxides during landing and takeoff in new aircraft in stages over the next 30 years. However, the development of more fuel-efficient engines by NASA and the engine manufacturers, which are resulting in higher nitrogen oxides emissions,[27] and the lack of economic incentives for airlines to support efforts to reduce nitrogen oxides emissions make the possibility of reaching these goals uncertain. In the last several years, increases in nitrogen oxides emissions from the more fuel-efficient engines have outpaced improvements made to reduce these emissions. Appendix VI provides more information on research to reduce nitrogen oxides emissions.

[27]The new fuel-efficient engines are operating at increasingly higher engine operating pressures. The nitrogen oxides emissions standards allow for increasing emissions as this pressure increases.

Adding to the uncertainty of introducing technologies to reduce nitrogen oxides is the limited federal funding for this research effort. NASA officials told us that in the past they developed their research to the full engine test level before engine manufacturers would take over responsibility for integrating the improvements into production-ready engines. However, budget cuts made in their emission research programs beginning in fiscal year 2000 have resulted in them ending their research at the engine component level below full engine testing. Figure 2 shows the funding for this program.

Figure 2: NASA's Planned Funding for Nitrogen Oxides Research



Sources: NASA (data), GAO (presentation).

Note: GAO analysis of information from NASA. Funding amounts are for the Ultra Efficient Engine Technology Program.

Industry officials and aviation experts agree on the importance of NASA's research and that NASA is focusing on the right mix of near-term and long-term technologies, but are critical of the amount of funding dedicated to nitrogen oxides reduction research. NASA's research to reduce nitrogen oxides is a component of its Ultra Efficient Engine Technology Program. The goal of this program is to develop technologies that will enable U.S. manufacturers to compete in the global marketplace for new commercial gas turbine engines. The current program is funded at $50 million per year. Industry representatives stated that shrinking budgets have made it difficult for NASA to maintain a level of effort at a critical mass for each

project within the Ultra Efficient Engine Technology Program. Furthermore, they added that engine manufacturers could not afford to work with immature technology when they are engaged in new engine development projects. This is because new engine developments are tied into projects with the airlines, and the engines must meet tight cost, schedule, and performance goals if they are to win market share.

The Ultra Efficient Engine Technology Program is a scaled-back version of a larger aeronautical research program that was terminated in fiscal year 2000. NASA officials said that budget cuts have reduced research in the current program by about 40 percent from the previous program. In the previous program, research was typically developed to the point where the technology was integrated into the full engine system. In the current program, funding is only available to incorporate the technology into engine components. The National Research Council has concluded that the current funding level jeopardizes achieving program results and does not carry the research far enough for the engine manufacturing industry to readily adopt it.[28]

As a result of the uncertainties surrounding emission reduction technology research, it is unclear when new production aircraft will, in the aggregate, start lowering landing/takeoff nitrogen oxides emissions on a per seat basis during the landing/takeoff cycle. Because of the 30-year projected life of new commercial aircraft, it could take decades before future new aircraft can contribute to nitrogen oxides reductions.

Concerns Over Emissions from Aircraft

Both the environmental and aviation communities have voiced concerns about the need to better control the growth of aircraft emissions, particularly nitrogen oxides. Air quality officials from the 13 states that have airports in nonattainment areas told us that emission standards for aircraft should be made more stringent for a number of reasons. For example, several of those officials said that available control measures for other air pollution sources have been nearly exhausted. They noted that aircraft have not been as strictly regulated as other sources, such as automobiles, and that reductions from aircraft may be needed in the future

[28]National Research Council, *For Greener Skies, Reducing Environmental Impacts of Aviation* (Washington, D.C.: National Academy Press, 2002).

for some areas to maintain attainment of the Clean Air Act's standards.[29] Likewise, in 2002, the National Academy of Science's National Research Council reported that the advances that have led to increased efficiencies in individual airplanes are not sufficient to decrease the total emissions of the global fleet, which is increasing in response to accelerating demand.[30] In the same vein, the Intergovernmental Panel on Climate Change reported in 1999 that "although improvements in aircraft and engine technology and in the efficiency of the air traffic control system will bring environmental benefits, these will not fully offset the effects of the increased emissions resulting from the projected growth in aviation."

Concerns about aircraft emissions have prompted calls for an improved approach for controlling them. For example, the National Research Council has recommended[31] that the U.S. government carry out its responsibilities for mitigating the environmental effect of aircraft emissions and noise with a balanced approach that includes interagency cooperation in close collaboration with the private sector and university researchers. The Council emphasized that the success of this approach requires commitment and leadership at the highest level as well as a national strategy and plan that, among other things, coordinates research and technology goals, budgets, and expenditures with national environmental goals. Along the same lines, a recent industry article on the environmental effectiveness of ICAO emission standards suggested that a programmatic framework is required to guide the development of a consensus on policy options for further reducing aircraft emissions.[32] Among the elements of the framework would be establishing the environmental need, the technical capability, the economic viability, and the regulatory consistency of each option.

[29]According to FAA official, aircraft are more heavily regulated than other mobile sources in terms of design, maintenance, and operation and have safety and noise regulations that other mobile sources lack.

[30]National Research Council, *For Greener Skies*, *Reducing Environmental Impacts of Aviation* (Washington, D.C.: National Academy Press, 2002).

[31]Ibid.

[32]Howard G. Aylesworth, Jr. and Peter Newton, "Qualitative Standards of the Environmental Effectiveness of International Civil Aviation Organization Emissions Standards and Recommended Practices," *Handbook of Airline Strategy: Public Policy*, *Regulatory Issues*, *Challenges*, *and Solutions* (Washington, D.C: Aviation Week, 2001).

Conclusion

Aviation's impact on local air quality is expected to grow as a result of projected increases in air travel. In addition, more attention will be focused on finding additional ways to reduce emissions from airports to enable localities to meet more stringent ozone standards, which go into effect in late 2003. In 1998, FAA, EPA, and industry officials established a stakeholders group to develop and implement a voluntary, nationwide program to reduce aviation-related nitrogen oxides emissions because they found the current approach—uncoordinated efforts by individual airports and states—inefficient for air carriers and potentially ineffective in reducing emissions nationwide. However, the stakeholders group has progressed slowly because of the complex nature of achieving consensus on all issues and, thus far, has not defined specific objectives or established time frames for achieving emissions reductions.

Despite its participation in the stakeholder group, FAA has not developed a long-term strategic framework to deal with these challenges. Moreover, FAA lacks a thorough study on the extent and impact of aviation emissions on local air quality. Without such management tools, FAA cannot assess the status or the effectiveness of its efforts to improve air quality. The study on aviation emissions prepared by the Intergovernmental Panel on Climate Change on aviation's effect on the global atmosphere provides a model for a study that FAA could perform to develop baseline information and lay a foundation for a strategic framework. Such a study could accomplish the goals of the study that the stakeholders group commissioned, but never completed, as well as create an opportunity for making public the substance of its deliberations and for incorporating this substance in a plan for reducing emissions. Once completed, such a study would provide baseline information for setting goals and time frames to measure progress in reducing aviation-related emissions.

Recommendation for Executive Action

We recommend that the Secretary, DOT, direct the Administrator of FAA, in consultation with the Administrator of EPA and Administrator of NASA, to develop a strategic framework for addressing emissions from aviation-related sources. In developing this framework, the Administrator should coordinate with the airline industry, aircraft and engine manufacturers, airports, and the states with airports in areas not in attainment of air quality standards. Among the issues that the framework should address are

- the need for baseline information on the extent and impact of aviation-related emissions, particularly nitrogen oxides emissions;

- the interrelationship among emissions and between emissions and noise;
- options for reducing aviation-related emissions, including the feasibility, cost, and emission reducing potential of these options;
- goals and time frames for achieving any needed emission reductions;
- the roles of NASA, other government agencies, and the aviation industry in developing and implementing programs for achieving needed emission reductions; and
- coordination of emission reduction proposals with members of ICAO.

Upon its completion, the Administrator, FAA, should communicate the plan to the appropriate congressional committees and report to them on its implementation on a regular basis.

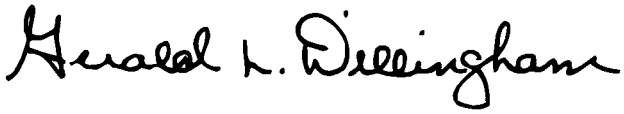
Agency Comments

We provided a draft of this report to the Department of Transportation, the Environmental Protection Agency, and the National Aeronautics and Space Administration for review and comment. FAA's Director, Office of Environment and Energy, and senior managers in EPA's Office of Air and Radiation provided oral comments and NASA's Deputy Director provided written comments. (See appendix VIII.) The three agencies generally concurred with our findings and recommendation and provided technical corrections, which we incorporated as appropriate. In addition, FAA indicated that our report provides a helpful overview on the aviation emissions issue from the perspective of multiple stakeholders dealing with this important issue. FAA also indicated that it is providing heightened attention to aviation emissions through multiple efforts including improving data and modeling, working with the international community on improved standards, and considering alternative approaches to encourage reductions in aviation-related, ground-based and aircraft emissions.

As agreed with your office, unless you publicly announce the contents of this report earlier, we plan no further distribution until 5 days from the report date. At that time, we will send copies of this report to interested congressional committees; the Secretary of Transportation; the Administrator, FAA; the Administrator, EPA; and the Administrator, NASA. We also will make copies available to others upon request. In

addition, the report will be available at no charge on the GAO Web site at http://www.gao.gov. Please call me at (202) 512-3650 if you or your staff have any questions concerning this report. Major contributors to this report are listed in appendix IX.

Sincerely yours,



Gerald L. Dillingham
Director, Physical Infrastructure Issues

Appendix I: Objectives, Scope, and Methodology

The Chairman of the Subcommittee on Aviation, House Committee on Transportation and Infrastructure asked us to provide information on the nature and scope of aviation's impact on air quality and the opportunities that exist to reduce emissions from aviation activities. Specifically, our research focused on (1) what efforts are being undertaken to reduce emissions from airport activities and what the outcomes are of these efforts, (2) what additional efforts are being undertaken by other countries to reduce aviation-related emissions, and (3) how improvements in aircraft and engine design have affected aircraft emissions.

To address the three questions, we interviewed and collected material from federal officials at the Federal Aviation Administration (FAA), Environmental Protection Agency (EPA), and National Aeronautics and Space Administration (NASA). We also interviewed and collected information from representatives of aviation associations, airlines, and aircraft manufacturers. We also interviewed officials from airports, state and local governments, and nongovernmental organizations. In addition, we reviewed our previous studies and those of EPA, the Natural Resources Defense Council, the International Panel on Climate Control, and other aviation-related environmental studies.

To address the first research question, we identified the nation's 50 busiest commercial service airports and determined that 43 of these airports are located in areas designated as nonattainment or maintenance with respect to requirements of the Clean Air Act. We reviewed and summarized environmental review documents submitted from 1997 through 2001 for the 43 airports to identify the nature of emissions from aviation activities and efforts to mitigate them. We also reviewed applicable sections of state implementation plans for the 13 states in which the 43 airports are located to identify emission-related sources and determine the nature of mitigation measures being undertaken. We also conducted comprehensive computer literature searches to identify the environmental effects of airport operations.

To also address the first research question and to provide information on the roles and responsibilities of states in relation to aviation-related emissions, we identified 13 states with airports located in air quality problem areas and conducted a telephone survey with state air quality authorities in these areas to obtain information on oversight/regulatory responsibilities for airport activities. We selected the states by first identifying the top 50 busiest commercial service airports on the basis of the number of air carrier landings and takeoffs in fiscal year 2001. In those states, 26 airports were identified as being located in areas designated as

nonattainment for ozone. The 26 airports are located in the following 13 states: Arizona, California, Georgia, Kentucky, Maryland, Massachusetts, Missouri, New Jersey, New York, Pennsylvania, Texas, Illinois, and Virginia. We reviewed applicable sections of the Clean Air Act, the National Environmental Policy Act, states' air quality laws, and International Civil Aviation Organization (ICAO) policies that defined air emissions standards applicable to aviation-related activities and agencies' role and responsibilities for administering them.

For the first research question, we also selected seven airports for case studies—Los Angeles International, Boston Logan International, Sacramento International, Dallas/Fort Worth International, Chicago O'Hare International, George Bush International/Houston, and Atlanta Hartsfield airports. We selected these airports on the basis of passenger traffic, air quality status, and initiatives undertaken to deal with airport-related emissions. At each location, we interviewed and gathered data from officials representing FAA and EPA regional offices, airports, state and local governments, and nongovernmental organizations on efforts to reduce emissions.

To address the second research question, we identified international efforts to reduce aviation-related emissions through our interviews with FAA, Department of State, ICAO, airport, airline, and nongovernmental agency officials. We conducted comprehensive computer literature searches to identify other international airports and to gather information on the efforts being undertaken by these airports to reduce aviation-related emissions. Our searches identified aviation reduction programs at European airports, including Switzerland and Sweden. We reviewed materials from Swiss and Swedish federal civil aviation officials on these efforts. We also reviewed proposed European Unions policies on reducing aviation-related emissions.

Finally, to address the third research question, we interviewed jet engine manufacturers, NASA researchers, and a university researcher to obtain information on efforts to reduce aircraft emissions. In addition, we calculated the landing and takeoff emissions for every aircraft model and engine combination in the U.S. 2001 commercial fleet for which data were available. Next, we looked for emission trends by identifying instances in which new model/engine combinations had been introduced in the last 5 years. We then compared the landing/takeoff emission characteristics of these newer aircraft with the emissions of the older aircraft they were most likely to replace. We identified examples of emissions trends for new aircraft. We did not perform a complete analysis of all trends.

In performing this analysis, we obtained the following information on every aircraft in the U.S. commercial aircraft fleet:

- specific model and engine,
- year 2001 landing/takeoff counts,
- aircraft age, and
- seating capacity.

This information came from AvSoft, a company that specializes in detailed data on commercial aircraft. We summarized this information for each specific model and engine combination. We then calculated the landing/takeoff emissions for each of these combinations using the Emissions and Dispersion Modeling System (EDMS), version 4.01 software developed by FAA for this purpose.

EDMS software calculates landing/takeoff emissions for four major criteria pollutants: carbon monoxide, volatile organic compounds, nitrogen oxides, and sulfur dioxides. The calculations take into account characteristics of specific aircraft model/engine combinations as well as airport-specific variations in the landing/takeoff cycle. We calculated the emissions for a representative "generic" airport using EDMS default values. Key values used in our EDMS calculations were

- emission ceiling height: below 3,000 feet;
- taxi-time: 15 minutes;[1] and
- takeoff weight: EDMS default value.

To determine the reliability of the software and data we used, we reviewed FAA's and AvSoft's quality controls, customer feedback information, and self-assessments. A weakness AvSoft identified with the data we used was a tendency to undercount the landings/takeoffs for smaller aircraft (aircraft with 70 seats or less). In addition, the EDMS software does not have complete information on some of the less common aircraft models and engines. This weakness, however, did not affect the trends we identified because of the limited use of these models and engines. On the basis of our experience working with the data and the software, we determined that the vendors were providing reliable products for the

[1]ICAO's analyses use 26 minutes as the default value for taxi-time. Our analysis of information provided by FAA indicated that 15 minutes was a more appropriate value for the large number of U.S. airports in our analysis.

purposes for which we used them and that additional data and software reliability assessments were not needed to support our conclusions.

During the review, the following aviation experts reviewed our methods and report drafts for accuracy and balance: John Paul Clarke of the Massachusetts Institute of Technology; Mary Vigilante of Synergy Consulting, Inc.; and Ian Waitz of the Massachusetts Institute of Technology.

Appendix II: Types, Amounts, and Impact of Emissions from Aviation-related Sources

Most emissions associated with aviation come from burning fossil fuels that power aircraft, the equipment that services them, and the vehicles that transport passengers to and from airports. The primary types of pollutants emitted by aircraft and airport-related sources are volatile organic compounds, carbon monoxide, nitrogen oxides, particulate matter, sulfur dioxide, toxic substances such as benzene and formaldehyde, and carbon dioxide, which in the upper atmosphere is a greenhouse gas that can contribute to climate change. When combined with some types of volatile organic compounds in the atmosphere, carbon dioxide forms ozone, which is the most significant air pollutant in many urban areas as well as a greenhouse gas in the upper atmosphere. Particulate matter emissions result from the incomplete combustion of fuel. High-power aircraft operations, such as takeoffs and climb outs, produce the highest rate of particulate matter emission due to the high fuel consumption under those conditions. Sulfur dioxide is emitted when sulfur in the fuel combines with oxygen during the combustion process. Fuels with higher sulfur contents produce higher amounts of sulfur dioxide than low-sulfur fuels. Ozone and other air pollutants can cause a variety of adverse health and environmental effects.

Aviation-Related Emissions and Sources

Aircraft emit pollutants both at ground level as well as over a range of altitudes. At most U.S. airports, aircraft can be a major source of air pollutants. The major air pollutants from aircraft engines are nitrogen oxides, carbon monoxide, sulfur dioxide, particulate matter, and volatile organic compounds. The burning of aviation fuel also produces carbon dioxide, which is not considered a pollutant in the lower atmosphere but is a primary greenhouse gas responsible for climate change. During the landing and takeoff cycles, and at cruising altitudes, aircraft produce different levels of air pollutant emissions. Emission rates for volatile organic compounds and carbon monoxide are highest when aircraft engines are operating at low power, such as when idling or taxiing. Conversely, nitrogen oxides emissions rise with an increasing power level and combustion temperature. Thus, the highest nitrogen oxides emissions occur during aircraft takeoff and climb out. In addition, aircraft have mounted auxiliary power units that are sometimes used to provide electricity and air conditioning while aircraft are parked at terminal gates and these units emit low levels of the same pollutants as aircraft engines. When flying at cruising altitudes, aircraft emissions, including carbon dioxide, nitrogen oxides, and aerosols that are involved in forming contrails and cirrus clouds, contribute to climate change.

Ground support equipment—which provide aircraft with such services as aircraft towing, baggage handling, maintenance/repair, refueling, and food service—is also a source of emissions at airports. This equipment is usually owned and operated by airlines, airports, or their contractors. According to EPA, the average age of ground support equipment is about 10 years, although some of the equipment can last more than 30 years with periodic engine replacement. Most ground support equipment is powered by either diesel or gasoline engines, and older engines pollute more than newer engines. Emissions from ground support equipment include volatile organic compounds, carbon monoxide, nitrogen oxides, and particulate matter. At some airports, airlines and the airport operators are introducing electric and alternative-fuel powered ground support equipment.

Emissions from passenger vehicles and trucks, referred to as ground access vehicles, are an important consideration at airports. Heavy traffic and congestion in and around airports result from the influx of personal vehicles, taxis and shuttles discharging and picking up passengers, and trucks hauling airfreight and airport supplies. Such traffic generates significant amounts of the emissions including carbon monoxide, volatile organic compounds, and nitrogen oxides. Several states that we surveyed indicated that automobiles are the major source of volatile organic compounds, carbon monoxide, particulate matter, and nitrogen oxides in areas with air quality problems at airports. This situation has occurred despite the fact that automobile emissions have been reduced on a per vehicle basis by 98 percent in the past 25 years.

Other sources of emissions at airports include construction activities, electric power generating plants, and maintenance operations. The air pollutants emitted by these activities can include particulate matter, nitrogen oxides, carbon monoxide, and sulfur dioxide.

The information available on the relative contribution of aviation-related activities to total emissions in an area is limited, but it indicates that these activities account for a small amount of air pollution and the proportion attributed to airports is likely to grow over time. According to EPA, aircraft, which are the only source of emissions unique to airports, currently account for about 0.6 percent of nitrogen oxides, 0.5 percent of carbon monoxide, and 0.4 percent of the volatile organic compounds emitted in the United States from mobile sources.[1] In cities with major

[1]Environmental Protection Agency, *National Air Quality and Emissions Trends Report, 1999*, EPA 454/R-01-004 (Washington, D.C.: March 2001).

airports, aircraft-related emissions could be higher or lower. In a 1999 study of 19 airports located in 10 cities,[2] EPA found that the proportion of nitrogen oxides emissions from mobile sources attributed to aircraft ranged from 0.6 percent to 3.6 percent in 1990. EPA also found that aircraft accounted for 0.2 percent to 2.8 percent of volatile organic compound emissions from mobile sources in the 10 cities during the period. From information contained in a recent study of emissions at Dallas/Fort Worth International Airport we estimated that aircraft produced about 3 percent of the nitrogen oxides and about 5 percent of the carbon monoxide present in the metropolitan area.[3] A 1999 study of emissions at Chicago O'Hare International Airport found that aircraft and the airport as a whole emitted about 1.6 percent and 2.6 percent of the total volatile organic compound emissions, respectively, within a 10-mile radius of the airport's terminal area and that nonairport sources were considerably more important to local air quality than aircraft.[4] In addition, a 2001 report on an air quality initiative for Boston Logan International Airport stated that the airport contributed less than 1 percent of the ozone-forming nitrogen oxides and volatile organic compound emissions in the Boston area.[5]

Little research has been done on how much of total area emissions (called an emissions inventory) are attributable to ground support equipment and airport-related road traffic, because they are categorized as nonroad and onroad mobile sources, both of which are already accounted for in emissions inventories. However, our analysis of the Dallas/Fort Worth International Airport emissions inventory indicated that ground support equipment contributed almost 3 percent of the nitrogen oxides emissions for the area. When all airport-related emissions are added together, we

[2]ICF Consulting Group, *Evaluation of Air Pollutant Emissions from Subsonic Commercial Jet Aircraft*, EPA420-R-99-013 (Washington, D.C.: April 1999). In this report, which was prepared for EPA, the agency acknowledged that some groups, including the air transport industry were critical of the growth projections, fleet turnover assumptions, and emissions estimates used in the report. As a result, these groups believe the report overstates the amount of emissions generated by aircraft.

[3]Dallas/Fort Worth International Airport, *Inventory of Air Emissions* (July 1998).

[4]The City of Chicago, *Findings Regarding Aircraft Emissions: O'Hare Airport and Surrounding Communities* (December 1999).

[5] Massachusetts Port Authority, *Air Quality Initiative for Boston Logan International Airport* (March 2001).

estimated that the Dallas/Fort Worth International Airport was responsible for 6 percent of nitrogen oxides in the metropolitan area.[6]

The amount of emissions attributable to each source varies by airport. According to a 1997 study of four airports,[7] ground access vehicles were the most significant source of mobile emissions, responsible for 45 to 68 percent of the airports' volatile organic compounds and 27 to 63 percent of the nitrogen oxides emitted from mobile sources.[8] Aircraft operations were found responsible for the next largest share of emissions from mobile sources, with total contributions of 15 to 38 percent and 26 to 37 percent for volatile organic compounds and nitrogen oxides, respectively. Ground support equipment accounted for 12 to 13 percent of total emissions from volatile organic compounds and 14 to 20 percent of total nitrogen oxides from mobile sources at the airports. The report also found that auxiliary power units for aircraft contributed a small amount of the emissions from volatile organic compounds and 9 to 20 percent of total nitrogen oxides emissions from mobile sources. According to the report, data on particulate matter emissions is not available for aircraft and auxiliary power units, but ground access vehicles contribute one type of particulate matter at 1.3 to 2.7 the rate emitted by ground support equipment.

Health and Environmental Impact of Pollutants

Some pollutants associated with aviation activities can increase the risk of a variety of health and environmental impacts. However, attributing these impacts to any particular source is extremely difficult because of the multiplicity of pollution sources in urban areas and the complexities involved in determining the exact causes of disease and environmental

[6]Our estimates were developed from information contained in Dallas/Fort Worth International Airport Emissions Inventory (July 1998) and emissions inventories for the Dallas/Forth Worth metropolitan area contained in that area's State Implementation Plan.

[7]Energy and Environmental Analysis, Inc., *Analysis of Techniques to Reduce Air Emissions at Airports*, (Arlington, VA: June 1997). The four airports included in this study, which was conducted for EPA, were Baltimore-Washington International Airport, Boston Logan International Airport, Los Angeles International Airport, and Phoenix Sky Harbor International Airport.

[8]According to EPA, mobile sources are moving objects that release pollution; mobile sources include cars, trucks, buses, planes, trains, motorcycles, and gasoline-powered lawn mowers. Mobile sources are divided into two groups: road vehicles, which include cars, trucks and buses, and nonroad vehicles, which include trains, planes, and lawn mowers. Mobile sources are distinguished from stationary sources, which are places or objects from which pollutants are released and which do not move around. Stationary sources include power plants, gas stations, incinerators, houses, etc.

damage. The limited amount of research available indicates that the impact of the pollutants associated with airport activities is no more pronounced in the areas near airports than it is in other urban areas. Nevertheless, the cumulative impact of pollution from all sources can affect health and the environment.

The pollutant of most concern in the United States and other industrial countries is ozone, which is formed when nitrogen oxides, some types of volatile organic compounds, and other chemicals are combined and heated in the presence of light in the atmosphere. Ozone been shown to aggravate respiratory aliments, such as bronchitis and asthma. Research has indicated that certain levels of ozone affect not only people with impaired respiratory systems, but healthy adults and children as well. Exposure to ozone for several hours at relatively low concentrations has been found to significantly reduce lung function and induce respiratory inflammation in normal, healthy people during exercise.[9]

In addition, according to EPA, there is growing public concern over emissions of air toxics, which include benzene, formaldehyde, and particulate matter, because of their potential adverse effects on health. Some of these emissions are associated with aviation activities. EPA's 1996 National Toxics Inventory indicates that amounts of hazardous air pollutants produced by aircraft are small relative to other sources such as on-road vehicles. However, EPA's national estimates are based on limited data, and very little data is available on toxic and particulate matter emissions in the vicinity of airports. A study of emissions at Los Angeles International Airport is expected to shed some light on the subject. In addition, FAA is involved in a study on identifying methods to measure aircraft particulate matter emissions.

In the upper atmosphere, aircraft emissions of carbon dioxide and other greenhouse gases can contribute to climate change. Greenhouse gases can trap heat, potentially increasing the temperature of the earth's surface and leading to changes in climate that could result in such harmful effects as coastal flooding and the melting of glaciers and ice sheets. According to a 1999 report by the Intergovernmental Panel on Climate Change, conducted under the auspices of the United Nations, global aircraft emissions in

[9]Environmental Protection Agency, *Environmental Fact Sheet: Adopted Aircraft Emissions Standards* (EPA 420-F-97-010, April 1997) and Federal Aviation Administration, *Air Quality Procedures For Civilian Airports and Air Force Bases* (Washington: April 1997).

general accounted for approximately 3.5 percent of the warming generated by human activities.[10] Jet aircraft are also the largest source of emissions generated by human activity that are deposited directly into the upper atmosphere. Carbon dioxide is the primary aircraft emission; it survives in the atmosphere for over 100 years and contributes to climate change. In addition, other gases and particles emitted by jet aircraft including water vapor, nitrogen oxides, soot, contrails, and sulfate combined with carbon dioxide can have two to four times as great an effect on the atmosphere as carbon dioxide alone, although some scientists believe that this effect requires further study. The Intergovernmental Panel on Climate Change concluded that aircraft emissions are likely to grow at 3 percent per year and that the growing demand for air travel will continue to outpace emission reductions achieved through technological improvements, such as lower emitting jet engines.

Table 6 summarizes the possible environmental effects of the major pollutants associated with aviation related activities on the human health and the environment.

[10]Intergovernmental Panel on Climate Change, *Aviation and the Global Atmosphere* (1999).

Table 6: Health and Environmental Effects of Air Pollutants

Pollutant	Health effects	Environmental effects
Ozone	Lung function impairment, effects on exercise performance, increased airway responsiveness, increased susceptibility to respiratory infection, increased hospital admissions and emergency room visits, pulmonary inflammation, and lung structure damage (long term).	Crop damage, damage to trees, and decreased resistance to disease for both crops and ecosystems.
Carbon monoxide	Cardiovascular effects, especially in those persons with heart conditions.	Adverse health effects on animals similar to effects on humans.
Nitrogen oxides	Lung irritation and lower resistance to respiratory infections.	Acid rain, visibility degradation, particle formation, contribute toward ozone formation, and act as a greenhouse gas in the atmosphere and, therefore, may contribute to climate change.
Particulate matter	Premature mortality, aggravation of respiratory and cardiovascular disease, changes in lung function and increased respiratory symptoms, changes to lung tissues and structure, and altered respiratory defense mechanisms.	Visibility degradation, damage to monuments and buildings, safety concerns for aircraft from reduced visibility.
Volatile organic compounds	Eye and respiratory tract irritation, headaches, dizziness, visual disorders, and memory impairment.	Contribute to ozone formation, odors, and have some damaging effect on buildings and plants.
Carbon dioxide, water vapor, and contrails	None.	Act as greenhouse gases in the atmosphere and, therefore, may contribute to climate change.
Sulfur dioxide	Respiratory irritant. Aggravates lung problems, particularly for individuals with asthma.	Causes damage to crops and natural vegetation. In presence of moisture and oxygen, sulfur dioxide converts to sulfuric acid, which can damage marble, iron, and steel.

Source: EPA and FAA.

Appendix III: Federal, State, and International Responsibilities for Controlling Aviation-related Emissions

The federal government and the states have responsibility for regulating sources of aviation emissions under the Clean Air Act, which was established to improve and protect air quality for human health and the environment.[1] In addition, a United Nations entity, the International Civil Aviation Organization (ICAO), establishes international aircraft emissions standards, studies aviation emissions-related issues, and provides guidance for controlling these emissions. ICAO includes 188 member countries, which have agreed to adopt, to the extent possible, standards set by ICAO.

For aircraft or aircraft engine emissions, the Clean Air Act gives EPA the authority[2] to establish emission standards. EPA, in consultation with FAA, has chosen to adopt the international emissions standards established by ICAO. FAA serves as the United States' representative to ICAO's Committee on Aviation Environmental Protection, which is responsible for assessing aviation's impact on the environment and establishing the scientific and technological basis for new gaseous emissions standards for aircraft engines. The committee has established several working groups to identify and evaluate emissions-reduction technology and operational measures and market-based options to reduce emissions. Both FAA and EPA participate in these working groups. In addition, FAA is responsible for monitoring and enforcing U.S. manufacturers' compliance with aircraft emissions standards, which it does in part through its process for certifying new aircraft engines.

In addition, the federal government plays a role in developing technologies to reduce aircraft emissions. NASA, in partnership with the aviation industry and universities, conducts research into improving the capabilities and efficiency of commercial aircraft. Part of this effort includes developing more fuel efficient and lower emitting engines. Over the years, NASA has been credited with contributing to technologies that have significantly lowered the amount of fuel consumed by jet engines; this in turn has reduced some emissions, particularly the greenhouse gas, carbon dioxide.

[1]42 U.S.C 7401-7626. The amendment to the Clean Air Act in 1990 provided for a number of related programs designed to protect health and control air pollution. The 1990 amendments established new programs and made major changes in the ways that air pollution is controlled. See U.S. General Accounting Office, *Air Pollution: Status of Implementation and Issues of the Clean Air Act Amendments of 1990*, GAO/RCED-00-72 (Washington, D.C.: Apr.17, 2000).

[2]See 42 U.S.C. 7571 of the Clean Air Act.

Under the Clean Air Act, EPA has jurisdiction for establishing national standards for all other mobile sources of emissions, including those associated with airport operations—such as ground support equipment and ground access vehicles such as automobiles, trucks, and buses operating on airport property. In establishing these emissions standards, EPA is to take into consideration the time it takes to develop the necessary technology and the cost of compliance.

The Clean Air Act also directs EPA to establish national standards for ambient air quality, and these standards can affect airport operations and expansion plans. EPA has set National Ambient Air Quality Standards for carbon monoxide, lead, nitrogen dioxide, particulate matter, ozone, and sulfur dioxide. EPA has labeled them criteria pollutants because the permissible levels established for them are based on "criteria" or information on the effects on public health or welfare that may be expected from their presence. The criteria pollutants are directly or indirectly generated by multiple sources, including airport activities. Local areas not meeting the standards for criteria pollutants are referred to as nonattainment areas. The act groups nonattainment areas into classifications based on the extent to which the standards for each criteria pollutant are exceeded and establishes specific pollution controls and attainment dates for each classification. The act has set 2010 as the deadline for extreme ozone nonattainment areas to meet the standards. (California is currently the only state with such an area).

The Clean Air Act also authorizes EPA to set ambient air quality standards; however, the states, which can adopt EPA's or their own more stringent standards, are responsible for establishing procedures to attain and maintain the standards. Under the act, states that have areas in nonattainment, must adopt plans—known as state implementation plans—for attaining and maintaining air quality standards and submit the plans to EPA for approval. State implementation plans are based on analyses of emissions from all sources in the area and computer models to determine whether air quality violations will occur. If data from these analyses indicate that air quality standards would be exceeded, the states are required to impose controls on existing emission sources to ensure that emissions do not exceed the standards. States can require control measures on airport emissions sources for which they are not preempted from regulating, such as power plants and ground access vehicles, and, to

a limited extent, ground support equipment.[3] However, states cannot control emissions from sources they are preempted from regulating including aircraft, marine vessels, and locomotives. If a state fails to submit or implement an adequate implementation plan, EPA can impose an implementation plan.

FAA is responsible for ensuring that its actions supporting airport development projects—such as providing funding for those projects—comply with federal environmental requirements, including those pertaining to air quality. The National Environmental Policy Act of 1969 sets forth a broad national policy intended to protect the quality of the environment. The act requires that federal actions receive an environmental review, which includes the impact on air quality, before federal decisions are made and actions are taken. For example, federally-funded proposals to construct airport runways require action by FAA. For airport projects, FAA is the lead agency responsible for the environmental reviews and for the approval of the airports' proposed design. EPA examines the environmental review documents prepared by FAA and other federal agencies.

The "general conformity rule" of the Clean Air Act directs federal agencies, such as FAA to ensure that federal actions at airports not delay the attainment or maintenance of ambient air quality standards. Therefore, FAA must determine, usually as part of the environmental review, that the estimated amount of emissions caused by a proposed federal action at an airport comply with the state implementation plan for meeting the standards. FAA cannot approve an action unless it complies with the plan. In order to demonstrate compliance, the airport could be required to implement emission control measures, such as converting airport vehicles to alternative lower emitting fuels.

To help carry out its responsibilities under the Clean Air Act and the National Environmental Policy Act, FAA developed the Emissions and Dispersion Modeling System, which is a computer model that estimates the amount and type of emissions from airport activities. FAA, airports,

[3]California is authorized, under section 209(e)(2)(B) of the Clean Air Act to enact and enforce nonroad engine standards, which apply to ground support equipment. States with nonattainment areas can promulgate standards identical to those of California. Otherwise, the federal standard applies. In November 2002, EPA adopted emissions standards for nonroad large spark emissions engines such as those used in much of the ground support equipment currently in service at airports.

and others use the model to assess the local air quality impacts of airport development projects. Typically, the model is used to estimate the amount of emissions produced by aircraft, ground support equipment, and other sources operating at the airport or in the nearby vicinity. The model also reflects the way these airport emissions are dispersed in the atmosphere due to wind and other factors. The dispersion analysis is intended to assess the concentrations of the emissions at or near the airport and, thereby, help to indicate the effect of the emissions on local air quality.

FAA is also engaged in several research projects to improve the understanding of aircraft emissions and methods for quantifying them. For example, FAA is working with the Society of Automotive Engineers to develop a protocol for measuring particulate matter emissions from aircraft. FAA is also studying ways to increase the accuracy of aircraft emission dispersion models and is analyzing the air quality impact of aircraft operations at or above 3000 feet.

Appendix IV: Efforts by Three States to Reduce Aviation-related Emissions

Three states with major commercial airports in nonattainment areas—California, Texas, and Massachusetts—have targeted airports for emissions reductions.

California

California has more major commercial airports—seven—than any other state, and all of them are located in nonattainment areas for ozone. Although none of the airports are a major source of ozone precursors such as nitrogen oxides and volatile organic compounds, California air quality authorities have turned their attention to airports as a source of reductions needed to reach and maintain attainment of ozone standards because they believe they have exhausted other sources, including large sources such as power plants and small sources like lawn mowers. The Los Angeles region is the only one in the country classified as an extreme nonattainment area for ozone. According to state environmental officials, emissions from all airport activities[1] contributed about 1 to 2 percent of the pollution in the Los Angeles region in 2000, and this is projected to increase to nearly 4 percent by 2020. State environmental officials attribute this projected increase in the airports' ozone contribution to an expected doubling of aircraft emissions coupled with a 50 percent decrease in emissions from other sources. These projections do not take into account the reductions in aircraft activity as a result of the events of September 11, 2001, and the financial uncertainties of the airline industry.

Because of the severity of the nonattainment level in the Los Angeles area, the state requires reductions from all sources, including airports, by 2010. Along with Los Angeles' local air quality agency, the California Air Resources Board has negotiated with EPA and airlines for a memorandum of understanding for voluntary emission reductions from ground support equipment.[2] According to California Air Resources Board officials, emission reductions would be achieved by replacing older, high polluting ground support equipment with new cleaner gas and diesel fueled equipment or equipment operating with alternative energy sources, such as electricity. In doing so, the officials expect an 80 percent reduction of emissions from ground support equipment that are used at five airports—

[1]The airports in the Los Angeles region include Burbank, Long Beach, Los Angeles International, John Wayne (Orange County), Ontario International, and Palm Springs International.

[2]The California Air Resources Board has reached agreement with the major carriers in Southern California to reduce emissions from ground support equipment.

Los Angeles International, Burbank, Ontario International, Long Beach, and John Wayne—in the Los Angeles region by 2010.

California's efforts to cut emissions from ground support equipment in the Los Angeles area are part of an aggressive statewide campaign to reduce airport pollution. In addition to using its limited authority under the Clean Air Act to implement airport related emissions reductions, the state has also established criteria for issuing air quality certifications provided for in federal law.[3] Under this law, before federal funds are allocated for projects involving a new airport, a new runway, or a major runway extension, the state governor must certify that there is reasonable assurance that the project will be "located, designed, constructed, and operated in compliance with applicable air and water quality standards." The state has developed a unique set of criteria for determining whether a proposed airport expansion project would have an impact on the environment. If the project exceeds one of the criteria, the airport is required to implement emissions mitigation measures in order to attain certification. For example, the certification for a runway project was invoked when the Sacramento International Airport planned to increase the number of parking spaces. The criteria on which the certification was based included annual increases of more than 7 million passengers or 139,000 aircraft operations (i.e., landings and takeoffs) or a permanent increase of more than 4,200 parking spaces. The airport's plans exceeded the number of parking spaces and, as a result, were required to implement emission mitigation measures in order to build the parking spaces. According to state officials, California is the only state to develop such criteria for certifying airport expansion projects. As of December 2002, three airports in California—Sacramento International, San Jose International, and Ontario International—have initiated expansion projects that required state certification.

Texas

Texas has four regions in nonattainment of national air quality standards for ozone, but the Houston and Dallas/Fort Worth regions have required the most extensive emission control measures for reaching attainment. These two regions contain the state's four largest airports—Dallas/Fort Worth International, Dallas Love Field, George Bush International/ Houston, and Houston Hobby—all of which are among the nation's 50 busiest airports. The Houston area has one of the worst ozone problems in

[3] 49 U.S.C. 47106.

the country and has been designated as a severe nonattainment area, requiring substantial control measures in order to comply with the Clean Air Act. Dallas-Fort Worth, on the other hand, has a much less serious ozone problem but has been penalized by EPA for not meeting its attainment schedule. EPA classified the Dallas/Fort Worth region as a moderate ozone nonattainment area in the early 1990s, which meant that the region was required to demonstrate attainment of the 1-hour ozone standard[4] by November 1996. However, air quality data from the region showed that the area failed to meet the attainment goal in 1996, which resulted in EPA reclassifying the severity level of the region from moderate to serious. The downgrading of the Dallas region's classification forced state and local authorities to develop a new state implementation plan with more extensive control measures. The state's environmental agency, the Texas Natural Resource Conservation Commission[5], included emissions from airport activities among the top ten highest sources of nitrogen oxides emissions from nonroad mobile sources in both the Dallas-Fort Worth and Houston regional areas.

Noting that the emissions inventories for both Houston and Dallas-Fort Worth placed airports in the top 10 sources for nitrogen oxides emissions of nonroad mobile sources, which contribute to ozone formation, the Texas Natural Resource Conservation Commission determined that control measures for each area were warranted. For Dallas-Fort Worth, the commission revised the state implementation plan for the area to include reduction of nitrogen oxides emissions from ground support equipment at both major commercial airports in the area—Dallas/Forth Worth International and Dallas Love Field. The plan called for a 90 percent reduction of nitrogen oxides emissions from ground support equipment by 2005. The airline industry challenged the state rule by filing a lawsuit, citing the Clean Air Act's preemption rule, which it argued prohibited states and local authorities from regulating ground support equipment. The lawsuit was dropped in October 2000 when the commission, the cities of Dallas and Fort Worth (which operates the major airports), and the affected airlines—American, Delta, and Southwest—reached a voluntary agreement to achieve a 90 percent reduction in nitrogen oxides emissions attributable to ground support equipment or other equipment by 2005. The

[4]The 1-hour ozone standard is the average amount of ozone allowed by EPA in the lower atmosphere during a one-hour period.

[5]The agency's name was recently changed to the Texas Commission on Environmental Quality.

commission brokered a similar agreement with the city of Houston as its operator of the airports and the affected airlines. Under both the Dallas/Fort Worth and Houston agreements, the affected carriers voluntarily agreed to reductions equivalent to 75 percent of nitrogen oxides emitted from ground service equipment and the cities—Dallas-Forth Worth, and Houston—as the operators of the airports agreed to be responsible for the remaining 15 percent to achieve the 90 percent reduction.

Massachusetts

The Boston area is classified as a serious ozone nonattainment area and state environmental officials are under increasing pressure by citizens, community groups, and industry to control emissions from Boston's Logan International Airport. State environmental officials have estimated that while only a small amount of total nitrogen oxides emissions in the area are attributable to aircraft, these emissions will continue to increase. They estimate that other emission sources at the airport, such as ground support equipment, will eventually begin to decrease as they are replaced by lower polluting equipment. The Boston airport is also consistently ranked as the airport with the second highest number of air travel delays in the nation. These air travel delays add to regional air quality problems because idling aircraft contribute to pollution. To meet a growing travel demand, Boston airport officials have proposed building a new runway to allow the airport to improve operating efficiency, thereby reducing emissions from idling aircraft. As part of this proposal, the airport also agreed that emissions would not exceed 1999 levels.

To address airport operation delays and reduce emissions, airport officials have considered three strategies—peak period pricing, emissions credit trading, and reducing emissions from ground support equipment.[6] Peak period pricing is a demand management strategy that raises landing fees during designated air traffic peak hours, which is expected to induce some air carriers to discontinue or reduce operations during peak periods. With fewer aircraft waiting to taxi and land during peak periods, emissions from aircraft would be reduced and regional air quality would be improved. An emissions credit trading program is designed to allow facilities to meet emission reduction goals by trading and transferring air emission credits with emission sources that surpassed their allotted targets. Used by EPA

[6]Air carrier representatives have noted that the airport's proposed strategies could be subject to legal challenge if they are implemented.

to reduce pollutants that contribute to acid rain, the emission credit trading program allows sources, such as industry, the flexibility to meet their reduction obligations in a more cost effective manner. Because emission credits are considered "additional" or "surplus" to those that are regulated and otherwise reduced under federal and state laws, they aid in achieving an overall decline in emissions regionwide, according to Boston airport officials. Similar to situations at the major airports in both California and Texas, state and airport officials have also focused on reducing emissions from ground support equipment.

In the wake of the events of September 11, 2001, which resulted in a reduction of flights and emissions at the Boston airport, the airport's operator—Massachusetts Port Authority—believes that peak pricing and emissions trading will not be needed to keep emissions below 1999 levels for several years. The Port Authority, however, continues to work with airport tenants to implement voluntary emission reduction strategies. In addition, in an August 2002 Record of Decision approving plans for a new runway and taxiways, FAA directed the Port Authority to develop and submit a plan for peak period pricing or other demand management strategies to reduce delays, which the Port Authority had committed to complete this plan as part of the state environmental review process, before initiating construction. In the Record of Decision, FAA pointed out that the program would have to comply with applicable federal constitutional and other requirements.

Appendix V: Airports' and Airlines' Efforts To Reduce Emissions

Many of the nation's busiest airports, in conjunction with air carriers, have voluntarily implemented control measures to reduce emissions by activities that include modifying the operating procedures of aircraft, using alternative fuels to run ground support equipment, and reducing the number of passenger vehicles entering and exiting the airport.

Aircraft

Although airports have no control over emissions from aircraft, they can encourage air carriers to reduce emissions as much as possible through modified operating procedures. For example, limiting the number of running engines during taxiing of aircraft can reduce the emission of nitrogen oxides and volatile organic compounds. According to airport officials at the Boston Logan International Airport, some pilots use single-engine taxiing with some aircraft to reduce emissions. Another example is reducing the use of engine reverse thrust to slow an aircraft to taxi speed after it lands. This procedure reduces nitrogen oxides emissions, but it may occur at the expense of slightly higher emissions of volatile organic compounds if the taxi time is increased because a runway turnoff is missed. Many factors are involved in the decision to use reverse thrust, including runway length and width, runway surface and taxiway conditions, weather conditions, and aircraft type.

Modifying the operating procedures of aircraft does not require additional equipment or aircraft modifications, but it is done at the discretion of the pilot. Under federal regulations, the commanding pilot of the aircraft is responsible for the safety of the passengers, crewmembers, cargo, and the airplane, and any procedure that modifies aircraft operation is at the discretion of the pilot. In addition, modifications to operating procedures may not be feasible in all weather conditions, with all aircraft, and/or at all airports.

Ground Support Equipment

Most ground support equipment used by air carriers at airports is fueled by gasoline or diesel. Replacing that equipment with cleaner-burning gas or diesel engines or equipment powered by alternative fuels—such as electricity, liquefied petroleum gas, and compressed natural gas—could result in reduced emissions. A reliable and comprehensive database of the ground support equipment in use does not exist; however, according to FAA, there are about 72,000 pieces of such equipment in operation. The Air Transport Association estimated that of the pieces of ground support equipment in used in 1999, about 30 to 40 percent operate on diesel fuel; 50 to 60 percent operate on gasoline; and about 10 percent use alternative fuels. Several airports we visited, including Los Angeles International,

Sacramento International, Dallas/Fort Worth International, Boston Logan International, and Atlanta Hartsfield, provided air carriers with the infrastructure necessary to operate alternatively fueled ground support equipment, and some carrier have begun converting their fleets of ground support equipment to alternative fuels. Los Angeles International, for instance, provided a varied alternative fuel infrastructure, including both compressed and liquefied natural gas refueling stations and electric charging stations, which offered air carriers different options to use alternative fueled equipment. Airport officials told us that air carriers have been using the alternative fuel stations to refuel their ground support equipment.

FAA reported[1] that replacing conventionally-fueled ground support equipment with alternatively-fueled equipment is the most cost effective way to reduce emissions at airports. Additionally, equipment originally designed to use the alternative fuels has less impact on the environment than equipment that is converted from using a conventional fuel to an alternative fuel; however, it is also more costly up front, and alternative fuel technology does not currently exist for some types of ground support equipment. Airports and air carriers use about 24 different types of ground support equipment, such as cargo loaders, aircraft pushback tractors, baggage tugs, and service trucks; and according to aviation industry officials, conversion of equipment from conventional to alternative fuel has had a mixed result in terms of operating the equipment. According to airline officials, liquefied petroleum and compressed natural gas vehicles require larger fuel tanks and are harder to operate; the cost for the alternative fuel infrastructure engines for ground support equipment is also very expensive. Air carriers and airports commonly have had to use a mixed fleet of liquefied petroleum and compressed natural gas and electric ground support equipment because of limitations of the various types of alternative fuel sources. For example, electricity has not been sufficiently powerful to run some of the ground service equipment that bear significant loads. In addition, some types of electric equipment do not work well in cold weather conditions. According to the Air Transport Association, for these and other reasons, no one equipment size or type fits all airlines' needs.

[1]Federal Aviation Administration, *Air Quality Procedures For Civilian Airports and Air Force Bases* (Washington, D.C.: April 1997).

Providing Electric Power at Gates

A trend at airports is to provide electricity and air conditioning service for aircraft at the gates, which can permit a reduction in the use of aircraft auxiliary power units and thereby reduce emissions, according to FAA. Airports are not required to install boarding gates that provide electricity to parked aircraft, but an FAA report notes that some airports have been proactive in reducing emissions and have invested in these electric gates.[2] The report explains that electric gates operate at greater energy efficiency than auxiliary power units, which support aircraft with power and ventilation systems when they are parked at the gates, and can substantially reduce emissions. Many airports, including Los Angeles International, Sacramento International, Dallas/Fort Worth International, and Boston Logan International provide electric power for parked aircraft, which allows aircraft to turn off their auxiliary power units while maintenance and cleaning crews prepare the aircraft for the next flight. However, air carriers are not required to use the electric gates, and some chose not to use them because they hinder the efficiency of their operations. For instance, one airline that specializes in getting its aircraft into and out of airports quickly—in 20 minutes or less—rarely uses the electricity provided by the airport, instead running the auxiliary power unit the entire time aircraft are at the gate, according to officials of that airline. These officials note that electric gates are only useful for those aircraft that are parked for 30 to 45 minutes or longer before they take off because of the time it takes to hook the aircraft up to the system.

Passenger Vehicles

Although EPA already regulates emissions from most passenger vehicles and trucks, options are available to further reduce emissions from theses sources at airports. Vehicles making trips to and from airports include employee and private passenger vehicles, airport and tenant-owned fleet vehicles, public transport vehicles and shuttles, and cargo vehicles for deliveries. All the airports we visited have implemented or are in the process of implementing emission reduction efforts for this emissions source. Some emission reduction measures that airports have applied to such ground access vehicles include the following:

- Dallas/Fort Worth International airport has consolidated its rental car facilities and, according to airport officials, the consolidation effort has reduced rental car related emissions by 95 percent. In addition, the single

[2]Federal Aviation Administration, *Air Quality Procedures For Civilian Airports and Air Force Bases* (Washington: April 1997).

shuttle service that resulted from consolidating the rental car facilities uses alternative fuel shuttles. George Bush Intercontinental/Houston plans to consolidate its rental car facilities; and Los Angeles International, Atlanta Hartsfield, and Boston Logan International are also considering the option.

- Dallas/Fort Worth International, Los Angeles International, and Sacramento International all have promoted some kind of employee/tenant commuter rideshare program. According to Los Angeles International Airport officials, about 25 percent of airport employees participate in a commuter rideshare program.
- Los Angeles International restructured its airport shuttle-van program in 1999 by reducing the number of shuttle vans authorized to make passenger pickups at the airport and requiring them to phase-in alternative fuel vehicles into their fleets. The airport expects all of the authorized operators to use alternative fuel vehicles by 2003. The airport is also considering requiring taxicabs serving the airport to operate on natural gas.
- Both Chicago O'Hare International and Dallas/Fort Worth International airports have built an electric automated transport system, also known as a "people mover," within the airport property to transport passengers between terminals. Chicago O'Hare International airport also offers direct rail service to the city center and provides alternative transportation to passengers and airport employees entering/exiting the airport. Los Angeles International provides alternative public transportation with a bus service that travels between the airport and the park-and-ride station at the Van Nuys Airport.

Other Measures

Airports have also reduced emissions from other sources, such as their on-site utilities plants. Los Angeles International airport's central utilities plant operates under a cogeneration energy saving system, which simultaneously generates electrical power and steam. Some electrical power is sold to the local electric company, and the steam provides heating and air conditioning (by powering steam refrigeration chillers) for the airport's buildings and central terminal area. According to airport officials, Los Angeles International receives more than $3 million in emissions credit each year for the emission controls achieved with its central utilities plant. Dallas/Fort Worth International airport also generates electricity with its solar power generators, which produce lower emissions than traditional powered generators. Airport officials stated that they have the capacity to build cogeneration plants using solar power and sell the power/surplus electricity to the state as well. The airport is trying to negotiate with federal agencies to receive credits for the amount of

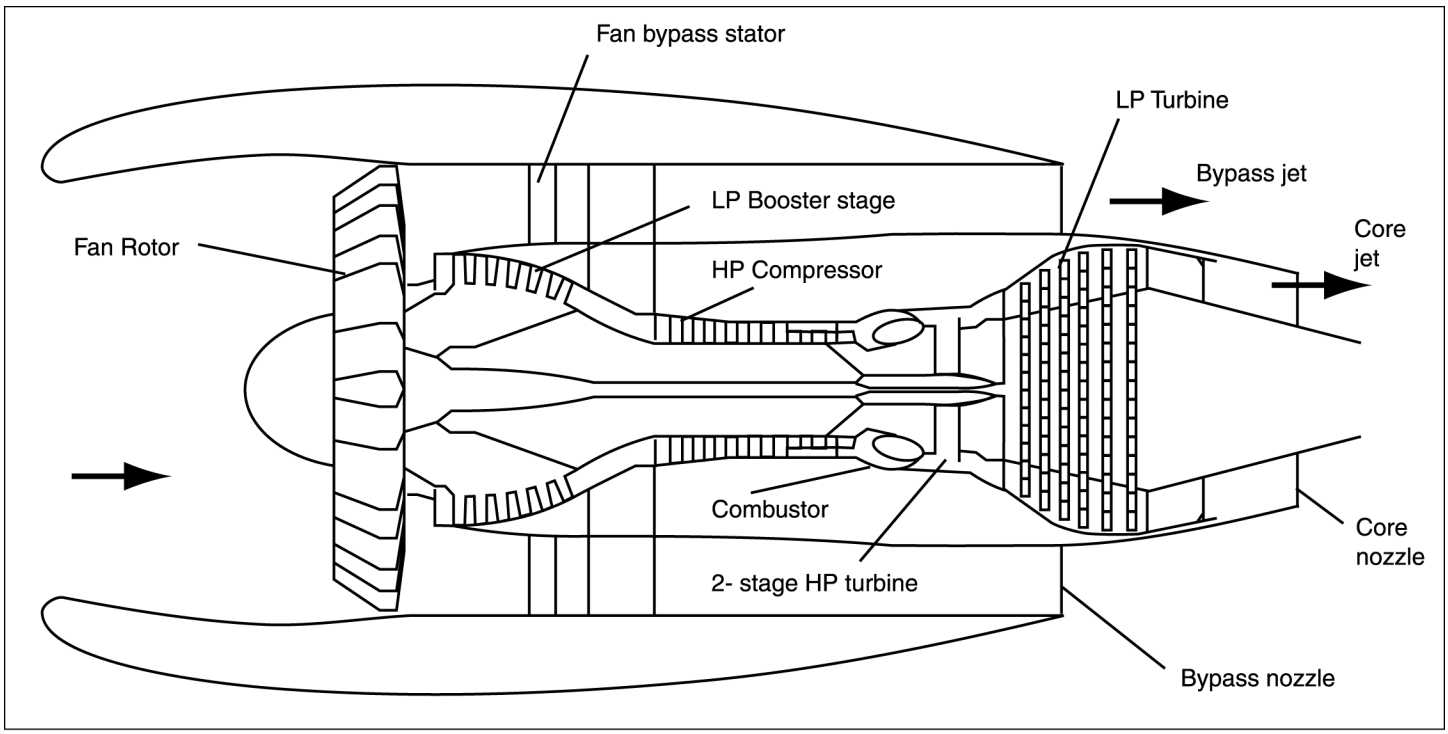
emission reductions achieved by using solar power energy and selling surplus electricity to the state. If successful, the airport could use these credits to gain approval of future expansion projects that increase emissions.

Appendix VI: Overview of Aircraft Fuel, Noise, and Nitrogen Oxides Reduction Technologies

Fuel efficiency improvements involve every aspect of an aircraft's design. Traditionally, about 40 percent of the improvements have come from airframe improvements and 60 percent from propulsive and engine improvements. Airframe improvements include improving the aerodynamic shape and structural efficiency (for example, reduced aircraft weight). Propulsive improvements have primarily resulted from increasing the size of the bypass fan and improving the shape of the bypass fan blades. Engine improvements have centered on increasing the pressure of the air that goes through the engine core (the engine operating pressure). The increased engine operating pressures allow more work to be extracted from a unit of fuel, thereby improving fuel consumption.

One of the first major technology breakthroughs with commercial jet engines occurred in the mid-1960s with the introduction of the turbofan jet engine (see figure 3). This design uses a bypass fan in front of the jet engine core to move much of the propulsive air and bypass the core of the jet that contains the compressor, combustor, and turbine. The primary motivation for this advancement was increased fuel efficiency. However, the reduced noise of this new design was an additional benefit. Noise was reduced because the bypass air moves at a slower speed than the air going through the core. Further noise reductions have evolved over time by increasing the size of the bypass fans and improving the shapes of the bypass fan blades. Researchers at NASA have indicated they are facing diminishing returns as they seek to reduce noise by further improving bypass fans and aircraft surfaces. They are also exploring more advanced technologies such as using electronics to actively control noise.

Figure 3: Major Components of a Turbofan Engine (Two-Shaft High Bypass Engine)



Legend

LP = Low pressure
HP = High pressure

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NASA, in association with jet engine manufacturers and the academic community, is working on several technologies to reduce nitrogen oxides emissions. NASA's research to reduce nitrogen oxide emissions is a component of its Ultra Efficient Engine Technology Program. The goal of this program is to develop technologies that will enable U.S. manufacturers to compete in the global marketplace for new commercial gas turbine engines. An important aspect of this program is reducing jet engine emissions of nitrogen oxides. NASA has set what it considers

ambitious goals[1] for its nitrogen oxides reduction research. These goals include the following:

- Demonstrate combustion technology, in a NASA test laboratory, that will reduce nitrogen oxides 70 percent relative to today's standard. This equates to a 20-50 percent reduction compared with the best engines being produced today.
- Demonstrate these technologies in engine combustor components by 2005.
- Hand off the technologies to manufacturers in a timely fashion so they can be incorporated in new engines in the 2007-2010 time frame.
- Study long-term concepts that could greatly reduce or eliminate nitrogen oxides emissions in the 2025-2050 time frame.

According to representatives from jet engine manufacturers, nitrogen oxides reduction research is complex and time consuming and requires specialized and expensive test equipment. They also said that basic research needed to understand the formation of nitrogen oxides in jet engines and to make significant changes to current engine designs is so expensive and lacking in marketplace investment rewards that no significant or sustained basic research in this area would take place without NASA taking the lead.

Adding to the complexities of this research is the extreme variation in jet engine designs. Other research and development by NASA and engine manufacturer is constantly raising engine-operating pressures as a way of improving fuel consumption and reducing greenhouse gas emissions. However, these developments tend to increase nitrogen oxides emissions, and further modifying engine designs to reduce nitrogen oxides has a direct impact on every other aspect of engine design: safety, operability, service life, operating costs, maintenance costs, and production costs. Jet engine manufacturers are taking divergent design approaches as they research how to maintain these other high-priority design characteristics while reducing nitrogen oxides emissions. As a result, NASA divides its resources over numerous projects.

[1]NASA officials told us that their nitrogen oxides research goals are more ambitious than what they expect to actually achieve when their research is incorporated into production ready engine designs. This is because designs that work well during component level research testing will undergo modification as the complete engine design is refined to meet safety and operability requirements and fuel-efficiency goals.

NASA's Ultra Efficient Engine Technology Program is scheduled to complete research and technology on aircraft engine combustor refinements that reduce the formation of nitrogen oxides so that the refinements can be introduced on aircraft by 2010. Because of the 30-year projected life of commercial aircraft, it could take decades before enough lower emitting aircraft are introduced in the commercial fleet to contribute to significant reductions in nitrogen oxides. NASA's nitrogen oxides research under the Ultra Efficient Engine Technology Program is centered on developing lean-burning rather than rich burning combustors that are in commercial service today. These lean-burning combustors will increase fuel/air mixing rates that, when combined with the lean fuel/air ratios, will reduce temperatures locally in the combustor and thus reduce the nitrogen oxides emissions generated. Because of funding constraints, NASA does not plan to implement the next phase of development, which is to examine the combustor improvements in a full engine test environment. NASA is relying on the engine manufacturers to implement this full engine development. Both NASA and aviation industry engineers said that this full engine development phase will be far more complex and involve many more design trade-offs than the combustor development phase. Additionally, they acknowledged that some of the nitrogen oxides reductions achieved during the combustor development phase would be lost during the full engine development phase. NASA researchers indicated these losses could be particularly severe because engine manufacturers are concurrently making other design changes to their engines to minimize fuel consumption and these changes will increase nitrogen oxides emissions. Consequently, NASA researchers are not sure how many of the improvements they expect to achieve by 2005 will survive as the engine manufacturers take over responsibility for completing the development of these improvements in a full engine test environment and then integrate these improvements into production-ready engines.

NASA is also working on a long-term revolutionary jet engine design that could significantly reduce all emissions including nitrogen oxides while also reducing fuel consumption. Under its "intelligent propulsions controls" design concept, engine functions are more precisely controlled using computers. For example, with this design, the number of ports delivering fuel to the engine combustion chamber would be greatly increased, and each port would be computer controlled. NASA officials are optimistic about the potential of this concept, but they added that research is in the early stages and that it will probably take 20 years or more to develop. NASA's overall long-term research plan calls for spending about $20 million per year over the next 5-year period to explore improved fuel burn and nitrogen oxides emission reduction technologies.

NASA researchers are also studying the possibility of developing zero emissions (except water) hydrogen-fueled aircraft with an electric propulsion system. While they note that there would have to be many breakthroughs in hydrogen storage and fuel cell technologies and high-powered lightweight electric motors before a hydrogen-fueled commercial airliner is feasible, they believe many of the needed breakthroughs could occur in the next 50 years.

NASA[2] is also researching nonengine methods that will indirectly reduce nitrogen oxides (and all other emissions) by reducing fuel consumption. This work includes more efficient airframes through aerodynamic improvements, structural improvements (i.e., reducing aircraft weight), and operational efficiencies (i.e., more fuel efficient flight routes, reduced taxi time). Historically, 40 percent of aviation fuel improvements have come from such efficiency improvements. Aviation emission experts emphasize that it is important that research into these types of improvements continue along with the engine research. The advantage of these improvements is that all emissions are reduced simultaneously without having to make emission trade-offs.

[2]FAA, the aviation industry, and universities also participate with this research.

Appendix VII: Additional Information on Our Analysis of Aircraft Emissions

Using the Emissions and Dispersion Modeling System (version 4.01) computer model developed by FAA and fleet data obtained from AvSoft, we calculated the landing/takeoff emissions for every aircraft model and engine combination in the U.S. commercial aircraft fleet during 2001. (See appendix I for additional information on our methodology.) Tables 7 and 8 provide additional information on our comparison of older and newest model Boeing 737s. As shown below, older model Boeing 737s, produced in 1969-1998, averaged 12.1 pounds of nitrogen oxides per landing/takeoff (see table 7), while the newest model Boeing 737s, produced in 1997-2201, averaged 17.9 pounds of nitrogen oxides per landing/takeoff (see table 8). Tables 9, 10, and 11 provide additional information about the calculations and commercial fleet for data presented earlier in this report.

Table 7: Emission Information for Older Boeing 737s during Landing/Takeoff

Model	Engine	Pounds NOx per LTO[a]	Pounds CO per LTO[a]	Pounds VOC per LTO[a]	Number in U.S. fleet in 2001	Number of LTOs in 2001	Oldest in fleet	Newest in fleet	Average number of seats	Pounds takeoff weight
737-200	JT8D-15	13.361	9.912	1.296	55	101,887	1977	1985	113.1	105000
737-200	JT8D-15A	11.835	10.475	1.479	65	85,577	1980	1988	113.7	105000
737-200	JT8D-17	14.804	9.574	1.165	21	31,620	1976	1987	106.6	105000
737-200	JT8D-17(Q)	14.804	9.574	1.165	1	879	1976	1976	128.0	105000
737-200	JT8D-17A	12.801	10.421	4.204	5	8,632	1983	1985	117.0	105000
737-200	JT8D-7B	11.207	10.424	2.326	1	181	1969	1969	56.0	100000
737-200	JT8D-9A	12.079	10.591	2.042	55	128,673	1968	1988	114.5	100000
737-200C	JT8D-15	13.361	9.912	1.296	1	2,139	1974	1974	111.0	105000
737-200C	JT8D-17	14.804	9.574	1.165	7	17,428	1979	1984	111.1	105000
737-200C	JT8D-17A	12.801	10.421	4.204	5	12,750	1983	1985	111.6	105000
737-200C	JT8D-9A	12.075	10.590	2.042	1	3,373	1980	1980	112.0	100000
737-300	CFM56-3B-1	10.720	19.197	1.201	380	842,336	1984	1997	130.8	122000
737-300	CFM56-3B-2	12.496	17.811	0.991	137	244,395	1984	1992	126.3	122000
737-300	CFM56-3C-1	14.195	16.766	0.859	9	12,355	1993	1998	126.9	122000
737-400	CFM56-3B-2	12.496	17.811	0.991	56	97,791	1988	1992	144.9	122000
737-400	CFM56-3C-1	14.350	16.771	0.861	41	71,175	1989	1999	138.9	133000
737-500	CFM56-3B-1	11.617	19.278	1.204	26	77,823	1990	1998	121.3	122000
737-500	CFM56-3B-2	13.578	17.894	0.994	3	5,188	1990	1990	104.0	122000
737-500	CFM56-3C-1	15.451	16.852	0.862	119	197,140	1990	1998	106.5	122000
Weighted averages[b]		12.123	16.798	1.221						
Total					**988**	**1,941,342**				
Percentage of total U.S. commercial fleet					12.7%	17.6%				

Legend
CO=carbon monoxide
LTO= landing/takeoff
NOx=nitrogen oxides
VOC= volatile organic compounds

Source: GAO.

Notes: Landing and takeoff data for U.S. aircraft in 2001 obtained from AvSoft. Emissions were calculated using FAA's Emissions and Dispersion Modeling System, version 4.01. The following variables were assumed to be the same for all aircraft: (1) taxi-time: 15 minutes, (2) auxiliary power unit time: 26 minutes, and (3) ceiling height for emissions mixing with local air: 3,000 feet. The model's default was used for takeoff weight.

[a]Pounds of emissions per one landing/takeoff (LTO), which includes emissions for takeoff, climb to 3,000 feet, approach, taxi, and auxiliary power unit.

[b]The average was computed by weighting the emissions for a specific model/engine combination by the number of landings/takeoffs for that combination in 2001.

Table 8: Emission Information for Newest Boeing 737s during Landing/Takeoff

Model	Engine	Pounds NOx[a] per LTO	Pounds CO per LTO	Pounds VOC per LTO	Number in U.S. fleet in 2001	Number of LTOS in 2001	Oldest in fleet	Newest in fleet	Average number of seats	Pounds takeoff weight
737-700	CFM56-7B-20	12.702	12.178	1.370	8	3,176	1998	2001	123.9	122000
737-700	CFM56-7B-22	15.078	11.269	1.183	118	218,184	1997	2002	136.9	122000
737-700	CFM56-7B-24	16.971	11.229	1.185	55	72,337	1998	2001	123.1	122000
737-700	CFM56-7B-26	20.280	9.926	1.001	5	2,435	2001	2001	124.0	122000
737-800	CFM56-7B-26	20.280	9.926	1.001	193	208,950	1998	2002	151.5	122000
737-800	CFM56-7B-27	22.181	9.663	0.934	54	33,181	2000	2002	157.0	122000
737-900	CFM56-7B-26	20.030	11.221	1.065	16	8,285	2001	2002	161.7	122000
Weighted averages[b]		17.883	10.651	1.097						
Total					**449**	**546,548**				
Percentage of total U.S. commercial fleet					5.75%	4.96%				

Legend
CO=carbon monoxide
LTO=landing/takeoff
NOx=nitrogen oxides
VOC=volatile organic compounds

Source: GAO.

Notes: Landing and takeoff data for U.S. aircraft in 2001 obtained from AvSoft. Emissions were calculated using FAA's Emissions and Dispersion Modeling System, version 4.01. The following variables were assumed to be the same for all aircraft: (1) taxi-time: 15 minutes, (2) auxiliary power unit time: 26 minutes, and (3) ceiling height for emissions mixing with local air: 3,000 feet. The model's default was used for takeoff weight.

[a]Pounds of emissions per one landing/takeoff (LTO), which includes emissions for takeoff, climb to 3,000 feet, approach, taxi, and auxiliary power unit.

Table 9: Additional Information on Comparison of Older and Newest Model Boeing 737 Landing/Takeoff Emissions

	Average emission per landing/takeoff		
Emission	Older Boeing 737 (pounds)	Newest Boeing737 (pounds)	Changes
Nitrogen oxides	12.1	17.8	47% increase
Carbon monoxide	16.8	10.7	37% decrease
Hydrocarbons	1.2	1.1	10% decrease

Source: GAO.

Notes: Landing and takeoff data for U.S. aircraft in 2001 obtained from AvSoft. Emissions were calculated using FAA's Emissions and Dispersion Modeling System , version 4.01. The following variables were assumed to be the same for all aircraft: (1) taxi-time: 15 minutes, (2) auxiliary power unit time: 26 minutes, and (3) ceiling height for emissions mixing with local air: 3,000 feet. The model's default was used for takeoff weight.

The U.S. 2001 commercial fleet included 988 older Boeing 737s. They accounted for 17.6 percent of this fleet's landings and takeoffs and 13.4 percent of this fleet's nitrogen oxides emissions during landing and takeoffs. The U.S. 2001 commercial fleet included 449 newer Boeing 737s. They accounted for 5.0 percent of this fleet's landings and takeoffs and 5.5 percent of this fleet's nitrogen oxides emissions during landing and takeoffs. See table 2 also.

Table 10: Additional Information on Comparison of Boeing 747 and 777 Emissions on a Per Aircraft Basis

	Emission per aircraft during landing/takeoff		
Emission	Boeing 747-400 (pounds)	Boeing B777-200ER (pounds)	Changes
Nitrogen oxides	103.5	124.2	20 percent increase
Carbon monoxide	47.7	30.4	36 percent decrease
Hydrocarbons	4.1	2.4	41 percent decrease

Source: GAO.

Notes: Landing and takeoff data for U.S. aircraft in 2001 obtained from AvSoft. Emissions were calculated using FAA's Emissions and Dispersion Modeling System, version 4.01. The following variables were assumed to be the same for all aircraft: (1) taxi-time: 15 minutes, (2) auxiliary power unit time: 26 minutes, and (3) ceiling height for emissions mixing with local air: 3,000 feet. The model's default was used for takeoff weight. See table 3 also.

The Boeing B77-200ER data is the weighted average (based on 2001 landings and takeoffs) for three different engines. The nitrogen oxides and other emission characteristics of these engines vary significantly.

The 58 Boeing 747-400s in the 2001 U.S. fleet have PW4056 engines and average 361 seats per aircraft. The 101 Boeing 777-200ERs in the 2001 U.S. fleet have the following engines: PW4090 (37 aircraft averaging 302 seats), GE90-90B (16 aircraft averaging 283 seats), and TRENT 892B-17 (48 aircraft averaging 249 seats). The three engine types for the Boeing 777-200ERs emit 138.6, 123.6, and 112.3 pounds of nitrogen oxides emissions per landing/takeoff, respectively.

Table 11: Comparison of Power, Engine Operating Pressures, and Nitrogen Oxides Emissions for a Boeing 737-300 and Its Most Common Replacement

	Older model B737-300	Newer model B737-700
Engine variant:	CFM56 3B-1	CFM56 7B-22
Power (thrust) per engine:	89 kiloNewtons	101 kiloNewtons
Engine operating pressure ratio:	22.4	24.41
Landing/takeoff nitrogen oxides emissions:	10.72 pounds	15.08 pounds

Source: GAO.

Notes: Aircraft engine emissions data obtained from ICAO. Calculations made using FAA's Emissions and Dispersion Modeling System, version 4.01. Landing/takeoff emission computations assume typical conditions of 3,000 foot mixing height, 15-minute taxi, and 26 minute auxiliary power unit usage and 122,000 pound takeoff weight. See table 5 also.

Other details:	B737-300	B737-700
Takeoff weight used for comparison:	122,000 lbs.	22,000 lbs.
Average seat count:	131	137
Number in 2001 commercial fleet:	380	118
Production years for U.S. fleet:	1984-1997	1997-present
Percent of 2001 commercial fleet landings/takeoffs:	7.7%	2.0%
Other landing/takeoff emissions in pounds:		
Carbon monoxide improved 41%:	19.20 lbs.	11.27 lbs.
Hydrocarbons improved 1.5%:	01.20 lbs.	01.18 lbs.

Appendix VIII: Comments from the National Aeronautics and Space Administration

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

February 27, 2003

Gerald L. Dillingham, PhD.
Director, Civil Aviation Issues
U.S. General Accounting Office
441 G. St. N.W.
Room 2T23
Washington, DC 20548

Dear Dr. Dillingham:

Thank you for giving us the opportunity to review and comment on (GAO) Draft Report: Aviation and the Environment: Strategic Framework Needed to Address Challenges Posed by Aircraft Emissions.

We concur with the report's conclusion that the Environmental Protection Agency and the National Aeronautics and Space Administration (NASA) should work together under the Federal Aviation Administration's leadership to develop a strategic framework for addressing emissions from aviation-related sources.

Comments on the report's content relative to NASA programs are provided in the enclosure. If we can be of further assistance, please do not hesitate to call Terrence Hertz at 358-4636.

Cordially,

Frederick D. Gregory
Deputy Administrator

Enclosure

Appendix IX: GAO Contacts and Staff Acknowledgments

GAO Contacts

Gerald L. Dillingham (202) 512-3650
Teresa Spisak (202) 512-3950

Staff Acknowledgments

In addition to the individuals named above, Carolyn Boyce, Joyce Evans, David Hooper, David Ireland, Art James, Jennifer Kim, Eileen Larence, Edward Laughlin, Donna Leiss, Jena Sinkfield, Larry Thomas, and Gail Traynham made key contributions to this report.

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