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AVIATION AND THE ENVIRONMENT

FAA's and NASA's Research and Development Plans for Noise Reduction Are Aligned but the Prospects of Achieving Noise Reduction Goals Are Uncertain



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Highlights of [GAO-08-384](#), a report to congressional committees

Why GAO Did This Study

Reducing aviation noise is important to the efficient operation and expansion of the National Airspace System because community opposition to aviation noise is a major obstacle to airport and runway development. Such development is needed to help address congestion and meet the nation's rapidly growing demand for air travel. The Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA) have the primary federal responsibility for research and development (R&D) on aviation noise. FAA focuses on the impacts of aviation noise on communities, while NASA focuses on noise at its source—aircraft engines and airframes. Both FAA and NASA have set noise reduction goals.

This congressionally requested report on aviation noise addresses (1) FAA's and NASA's R&D plans for addressing aviation noise and the extent to which they are aligned and (2) FAA's and NASA's noise reduction goals and the likelihood that these goals will be achieved.

To conduct its work, GAO reviewed FAA's and NASA's R&D planning documents, coordinating mechanisms, and research plans and interviewed agency officials. In addition, aviation industry representatives reviewed and commented on a draft of this report. A draft was provided to FAA and NASA. Both agencies had no comment.

To view the full product, including the scope and methodology, click on [GAO-08-384](#). For more information, contact Gerald L. Dillingham at (202) 512-2834 or dillingham@gao.gov.

AVIATION AND THE ENVIRONMENT

FAA's and NASA's Research and Development Plans for Noise Reduction Are Aligned, but the Prospects of Achieving Noise Reduction Goals Are Uncertain

What GAO Found

FAA's and NASA's R&D plans include a wide range of projects for addressing aviation noise, and these plans are aligned through partnerships and planning and coordinating mechanisms. FAA sponsors aviation noise R&D in areas such as aviation noise measurement, aviation noise effects, aviation noise and emissions interrelationships, and flight procedures and technologies to mitigate the impact of noise on communities. FAA sponsors much of this research through partnerships with universities; other federal agencies, including NASA; and industry. NASA conducts R&D that can eventually lead to new technologies for making substantially quieter aircraft provided that the technologies are further developed by industry and integrated into production-ready aircraft designs. FAA and NASA have aligned their aviation noise R&D activities by working with interagency planning and coordinating groups to establish objectives for the nation's aeronautical research and for specific research on the environmental impacts of next generation aviation technologies. Both agencies also serve on the same aviation research advisory groups, and the alignment of their aviation noise R&D activities is reflected in strategic plans for the National Airspace System that indicates how each agency's R&D efforts will contribute to meeting goals for reducing noise and thereby help reduce community opposition to increasing aviation system capacity.

FAA's and NASA's noise reduction goals are designed, together, to reduce people's exposure to aviation noise primarily by reducing such noise at its source, but the likelihood of achieving these goals is uncertain. Under FAA's targets, the number of people exposed to significant aviation noise—estimated at 500,000 nationwide—would be reduced by 4 percent a year through fiscal year 2012. NASA's targets, established for the next three generations of aircraft, would lead to the entry into service of successively quieter aircraft by 2015, 2020-2025, and 2030-2035, respectively. The likelihood of meeting these targets depends on a number of uncertainties. First, federal funding will be needed not only for NASA's research but also for later-stage R&D, which NASA expects others to perform. The administration has proposed a 10-year program to support later-stage R&D to demonstrate technologies for industry acceptance. But even if funded, the development of noise reduction technologies may be limited by concerns about global warming, since advances in these technologies could make it more difficult to also achieve reductions in aircraft emissions of greenhouse gases. Also uncertain is the extent to which manufacturers will integrate newly developed technologies into aircraft and engine designs. Finally, it is uncertain whether airlines will purchase new aircraft or retrofit existing aircraft with the new technologies in sufficient numbers to achieve targeted reductions in exposure to aviation noise. Failure to achieve FAA's and NASA's noise reduction goals could constrain efforts to expand the National Airspace System's capacity and reduce congestion.

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Abbreviations

ADS-B	Automatic Dependent Surveillance-Broadcast
AIP	Airport Improvement Program
CDA	Continuous Descent Arrival
CLEEN	Continuous Lower Energy, Emissions and Noise
dB	decibel
DNL	day-night level
EPN	effective perceived noise
FAA	Federal Aviation Administration
ICAO	International Civil Aviation Organization
JPDO	Joint Planning and Development Office
MOU	memorandum of understanding
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NextGen	Next Generation Air Transportation System
NRA	NASA Research Announcement
OSTP	Office of Science and Technology Policy
PARTNER	Partnership for Air Transportation Noise and Emissions Reductions
PFC	passenger facility charge
R&D	research and development
REDAC	Research, Engineering, and Development Advisory Committee

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United States Government Accountability Office
Washington, DC 20548

February 15, 2008

The Honorable Mark Udall
Chairman
The Honorable Tom Feeney
Ranking Member
Subcommittee on Space and Aeronautics
Committee on Science and Technology
House of Representatives

The Honorable Jerry Costello
Chairman
The Honorable Thomas Petri
Ranking Republican Member
Subcommittee on Aviation
Committee on Transportation and Infrastructure
House of Representatives

Aviation noise continues to be a challenge to the operation and expansion of the National Airspace System (NAS). Air traffic has grown steadily over the past 5 years and is expected to continue growing as more flights are required to carry the 1 billion passengers anticipated by 2015. To handle the forecasted growth, the Joint Planning and Development Office (JPDO), an interagency organization within the Department of Transportation's Federal Aviation Administration (FAA), is working to plan a new air traffic management system, the Next Generation Air Transportation System (NextGen). Critical objectives for NextGen are to improve the overall safety and increase the efficiency of the NAS. Achieving these objectives will involve the implementation of new technologies and air traffic control procedures; airspace redesigns; and infrastructure developments, including new or expanded runways and airports. However, community opposition to these developments is a major challenge, largely because of concerns about aviation noise. According to JPDO's 2007 Concept of Operations document, current operational trends show that environmental impacts will be the primary constraint on the capacity and flexibility of the NAS unless these impacts are managed and mitigated. Legislative

proposals to reauthorize FAA¹ include a number of provisions designed to address aviation noise issues.

To address aviation noise and its impacts, the federal government follows a “balanced approach” recommended by the International Civil Aviation Organization (ICAO).² This balanced approach recognizes that short-term opportunities to mitigate the impacts of noise on communities through noise abatement programs, the soundproofing of residences and public buildings, and operational restrictions on aircraft should be combined with longer-term efforts to reduce aviation noise. Such longer-term efforts include reducing noise at its source through more stringent noise standards and supporting research and development (R&D) to make aircraft quieter, developing and implementing NextGen technologies and procedures, and encouraging compatible land use. As part of this balanced approach, FAA and the National Aeronautics and Space Administration (NASA) have the principal federal responsibility for R&D to address aviation noise. FAA, through its partnerships with universities and through JPDO, supports a broad range of research on measuring and reducing the impacts of noise on communities, while NASA’s research program focuses on reducing noise at its source—in aircraft engines and airframes. NASA, in partnership with the aircraft and engine manufacturing industry, has contributed to a number of advancements in aircraft engine and airframe technology that have substantially reduced the amount of noise produced by aircraft and may lead to further reductions, depending on the extent to which current research leads to noise-reducing aircraft engine and airframe designs and other factors. FAA and NASA have set technology goals for reducing aviation noise. For example, FAA has set a system-level goal of a 4 percent yearly reduction in the number of people exposed to significant aviation noise.

You requested that we study noise and other environmental impacts of aviation that may fundamentally constrain air transportation in the 21st century. In October 2007, we testified before the Subcommittee on Aviation, House Transportation and Infrastructure Committee, on the impacts of aviation noise on efforts to expand the capacity of airports and

¹H.R. 2881 and S. 1300.

²ICAO is an advisory organization affiliated with the United Nations that aims to promote the establishment of international civil aviation standards and recommended practices and procedures.

the NAS.³ This report provides additional information on aviation noise, focusing particularly on FAA's and NASA's R&D related to this issue and on the ability of the two agencies to achieve their respective noise reduction goals through their R&D on aviation noise. Specifically, we addressed the following questions:

1. What are FAA's and NASA's R&D plans for addressing aviation noise and to what extent are these plans aligned?
2. What are FAA's and NASA's noise reduction goals, and what is the likelihood that the established goals will be achieved?

To determine FAA's and NASA's aviation noise R&D plans, we reviewed FAA and NASA R&D planning documents and other information provided by these agencies on their near-term and long-term goals. To determine the extent to which FAA's and NASA's aviation noise-related activities are aligned to meet noise reduction goals, we obtained and analyzed information on mechanisms in place to coordinate noise R&D activities, such as JPDO's Environmental Working Group and FAA's Research, Engineering, and Development Advisory Committee (REDAC). We also compared FAA's and NASA's R&D plans to determine whether they are complementary and in line with JPDO's and the Executive Office of the President's Office of Science and Technology Policy's (OSTP) plans. We also analyzed how the agencies periodically assess the potential for synergies or gaps in research activities. In addition, we interviewed agency officials on the results of our analyses. To determine FAA's and NASA's noise reduction goals and the likelihood of meeting those goals, we reviewed FAA and NASA R&D planning documents and other information provided by the agencies. We also interviewed agency officials to obtain their views on the likelihood of meeting noise reduction goals within the established time frames. Three external aviation experts reviewed a draft of this report for accuracy and balance. We conducted this performance audit from November 2007 through February 2008 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

³GAO, *Aviation and the Environment: Impact of Aviation Noise on Communities Presents Challenges for Airport Operations and Future Growth of the National Airspace System*, [GAO-08-216T](#) (Washington, D.C.: Oct. 24, 2007).

Results in Brief

FAA's and NASA's R&D plans include a wide range of projects for addressing aviation noise, and these activities are aligned through partnerships and planning and coordinating mechanisms. FAA sponsors aviation noise R&D in a number of areas, including aviation noise measurement, the effects of aviation noise, the interrelationships between aviation noise and emissions, and flight procedures and technologies that can mitigate the impacts of noise on communities. FAA sponsors much of this research through partnerships with universities; other federal agencies, including NASA; and industry as part of its Partnership for Air Transportation Noise and Emissions Reduction (PARTNER) Center of Excellence.⁴ NASA is the federal agency primarily responsible for conducting R&D to reduce the amount of noise produced by aircraft engines and airframes. NASA's aviation noise efforts focus on what NASA refers to as "fundamental research", a stage of the R&D process that takes a technology to a point where it can be further matured by manufacturers and eventually incorporated into new aircraft or engine designs. These technologies have the potential to make the next generations of aircraft substantially quieter than today's aircraft—provided that industry further develop the technologies and manufacturers integrate them into production-ready aircraft. FAA and NASA have aligned their aviation noise R&D plans through a number of planning and coordinating mechanisms in order to ensure that these plans are complementary and contribute to goals for addressing the environmental impacts of aviation, particularly as these impacts relate to the implementation of NextGen. FAA and NASA have participated in planning and establishing objectives for the nation's aeronautical research through OSTP, within the Executive Office of the President, as well as for specific research to address the environmental impacts of NextGen as part of JPDO's Environmental Working Group. In addition, FAA and NASA sit on the advisory board of PARTNER, which also includes representatives from the aircraft manufacturing industry, airlines, airports, and communities. Furthermore, NASA is a member of FAA's REDAC, and FAA participates in reviews of NASA's aviation noise research program. FAA's and NASA's alignment of their aviation noise R&D activities is reflected in JPDO's strategic plans for NextGen, which indicate how each agency's R&D efforts will contribute to meeting goals for reducing noise and thereby help to address an impediment to increasing the aviation system's safety and efficiency.

⁴FAA Centers of Excellence are FAA partnerships with universities and affiliated industry associations and businesses throughout the country that conduct aviation research in a number of areas, including advanced materials, aircraft noise and emissions, and airworthiness.

In conjunction with their aligned R&D plans, FAA and NASA have set noise reduction goals, although the likelihood that these goals will be achieved depends on the implementation of noise reduction technologies developed through the agencies' research and other factors. FAA estimates that about 500,000 people in the United States are significantly impacted by aviation noise, and, under FAA's goal, the number of people exposed to aviation noise would decrease by 4 percent a year through fiscal year 2012.⁵ NASA's noise goals, established for the next three generations of aircraft, could lead to the entry into service of successively quieter aircraft. NASA's goals include a cumulative reduction⁶ in the effective perceived noise (EPN)⁷ of 32 decibels (dB)—expressed as a noise reduction of 32 EPN dB—relative to the current most stringent noise standard, for the next generation of aircraft expected to enter service in 2015. More aggressive NASA goals for the generations of aircraft entering service from 2020 through 2025 and from 2030 through 2035 are cumulative reductions of 42 EPN dB and 71 EPN dB, respectively, relative to the standard. NASA's goals would be achieved if noise reduction is the only aim; however, when other factors are considered, such as the need to reduce aircraft emissions, the noise reductions could be lower.

NASA officials stress that when NASA's research ends, it is up to industry to develop the technologies further. Thus, aircraft and engine manufacturers will then need to integrate the technologies into aircraft and engine designs, and there are no guarantees that these additional steps will be taken. According to FAA, additional funding is needed to ensure the continued development and use of near-term technologies to meet noise reduction goals for NextGen. To move noise reduction technologies beyond NASA's stage of development, the House fiscal year 2007 reauthorization proposal for FAA includes the Continuous Lower Energy, Emissions and Noise (CLEEN) initiative, which would create a program for the development, maturation, and certification of airframe technologies for aircraft over the next 10 years to reduce aviation noise

⁵This goal is measured by a 3-year moving average for calendar years 2000 through 2002. In fiscal year 2007, the noise exposure goal was revised from a 1 percent to a 4 percent cumulative reduction per year in the number of people exposed to significant aviation noise.

⁶The NASA goals are cumulative decreases that are obtained by adding together the decreases in an aircraft's maximum noise levels at take off, flyover, and approach.

⁷EPN is the noise measure used to establish compliance with noise certification standards.

and emissions.⁸ According to FAA, the program, in which NASA will participate as an adviser, is intended to accelerate near-term technology maturation and to demonstrate to aircraft and engine manufacturers the readiness of these technologies for incorporation into new aircraft and engine designs. Concern about other environmental problems, such as global warming and air quality, may also limit the likelihood of achieving FAA's and NASA's noise reduction goals, since it will be technologically challenging to design aircraft with reduced noise while, at the same time, achieving the significant reductions in greenhouse gases and other emissions that will be required. Furthermore, even if R&D efforts do lead to next generation aircraft that meet NASA's noise reduction goals, integrating these quieter aircraft into the fleet to the extent that they have a significant impact on noise reduction will be a challenge. Aircraft have a lifespan of about 30 years, and many of the aircraft in the current fleet are expected to be in operation for many years to come. In addition, the financial pressures facing many airlines will make it difficult for them to upgrade their fleets with new, quieter aircraft. Failure to achieve FAA's and NASA's noise reduction goals could have implications for the implementation of NextGen, because continued noise problems at airports could constrain efforts to increase the safety and efficiency of the NAS—a key component of the NextGen strategy.

We provided a draft of this report to the Department of Transportation and NASA for review and comment and neither had comments.

FAA and NASA Use Partnerships and Planning and Coordinating Mechanisms to Align R&D on Noise Reduction

FAA presently supports aviation noise R&D primarily in the areas of measuring and mitigating the impacts of aviation noise, while NASA focuses its efforts on technologies for reducing noise from aircraft engines and airframes, and the two agencies align their activities through partnerships and planning and coordinating mechanisms.

⁸A similar provision is in the Senate bill for FAA reauthorization. As of the date of this publication, the House and Senate are discussing the reauthorization bills.

FAA Supports Aviation Noise R&D Primarily through Partnerships with NASA, Academic Institutions, and the Aviation Industry

FAA's support of aviation noise R&D is part of its overall responsibility for reducing the impacts of aviation noise. In addition to R&D activities, FAA supports airports' efforts to mitigate aviation noise mainly through its voluntary noise compatibility program, known as the Part 150 Noise Compatibility Program,⁹ which provides guidance to airports on how to develop noise compatibility plans to mitigate noise on and around airports.¹⁰ FAA also administers grants through the Part 150 program that airports can use for noise mitigation efforts in areas exposed to significant aviation noise, defined as a 65 decibel day-night level (DNL 65 dB).¹¹

Airports that participate in the Part 150 program can receive noise set-aside funds from the Airport Improvement Program (AIP),¹² which they must match to varying degrees, depending on their size.¹³ These funds can be used to, among other things, develop plans for noise mitigation, soundproof buildings, and support relocation by acquiring homes in areas with significant noise. According to FAA, it has provided about \$5 billion in AIP grants, and airports have used about \$2.8 billion in passenger

⁹14 CFR 150.

¹⁰As part of its environmental responsibilities, FAA also works through ICAO to foster international environmental standards, including those for noise, as well as recommended practices and guidance materials.

¹¹The impact of aviation noise is usually analyzed in terms of the extent to which the noise annoys people by interfering with their normal activities, such as sleep, relaxation, speech, television viewing, and school and business operations. The generally accepted model for assessing the effects of long-term noise exposure is based on a correlation of the day-night average sound level, DNL, to the percentage of population highly annoyed by recurring noise sound events. DNL is a noise descriptor or metric that takes into account the magnitude of the sound levels of all individual events that occur during a 24-hour period, the number of events, and an increased sensitivity to noise during typical sleeping hours (between 10:00 p.m. and 7:00 a.m.). The correlation shows that the percentage of people highly annoyed by noise exposure increases significantly above DNL 65 dB. Some aviation noise consultants have noted disadvantages of DNL as a metric to measure noise and suggest the use of supplemental metrics that measure the frequency and intensity of individual noise events that may provide a more adequate measure of aviation noise as experienced by people. Some airports have included supplemental analysis such as the Number of events Above and the Time Above, within their noise studies. FAA requires the use of DNL for airport analysis but also allows for the use of supplemental metrics.

¹²The AIP program provides federal funds for development projects at the entire range of the nation's 3,400 airports—from small general aviation airports to the very largest airports that handle several million passengers per year.

¹³According to FAA, noise projects are eligible for 80 percent funding under AIP for large- and medium-hub airports and 95 percent funding at small, nonhub, general aviation, and reliever airports.

facilities charges (PFC)¹⁴ for Part 150 noise mitigation studies and projects. In total, this funding amounts to nearly \$8 billion for fiscal years 1982 through 2007 (see table 1).

Table 1: AIP and PFC Investments for Noise-Related Purposes for Fiscal Years 1982-2007

Dollars in millions	
AIP funds	Funding
Mitigation measures for residences	\$1,903
Land acquisition	2,170
Noise monitoring system	170
Mitigation measures for public buildings	703
Noise compatibility plan	87
Total AIP funds	\$5,033
PFC funds	
Multiphase	\$1,283
Land acquisition	481
Soundproofing	1,018
Monitoring	31
Planning	15
Total PFC funds	\$2,828
Grand total	\$7,861

Source: FAA.

FAA sponsors aviation noise R&D in a number of areas, including aviation noise measurement, the effects of aviation noise, the interrelationships between aviation noise and emissions, and flight procedures and technologies that can mitigate the impacts of noise on communities. FAA sponsors much of this research through partnerships with universities, other federal agencies, and industry. University research is generally part of FAA's Air Transportation Centers of Excellence program. One of these Centers of Excellence, PARTNER, has conducted numerous noise-related R&D projects. See appendix I for a list of PARTNER participants and projects. PARTNER is a cooperative research organization that includes 10 collaborating universities and approximately 50 advisory board members

¹⁴PFCs are fees that airports can charge passengers to fund FAA-approved projects. Not all airports charge these fees.

who represent aerospace manufacturers, airlines, airports, state and local governments, and professional and community groups. NASA, along with FAA and Transport Canada,¹⁵ is a sponsor of PARTNER. The collaborating universities and organizations represented on the advisory board provide equal matches for federal funds for research and other activities.

PARTNER projects related to aviation noise involve identifying a means to reduce aircraft landing noise, assessing the human health and welfare risks of aviation noise, developing online resources to better inform the public about aviation noise issues, and testing alternative aircraft descent patterns. For example, researchers are developing an integrated suite of three analytical tools—the Environmental Design Space, the Aviation Environmental Design Tool, and the Aviation Environmental Portfolio Management Tool—that can be used to identify interrelationships between noise and emissions. Data from these three tools will allow for assessing the costs and benefits of aviation environmental policy options. PARTNER has also designed and flight tested a nighttime Continuous Descent Arrival (CDA) procedure for the Louisville International Airport.¹⁶ This procedure is expected to allow aircraft to remain at cruise altitudes longer as they approach destination airports, use lower power levels, and thereby lower noise and emissions during landings. United Parcel Service plans to begin using the CDA procedure for its operations at Louisville International Airport in the near future. Other PARTNER projects include an effort to assess sonic booms from a new supersonic business aircraft and studies to better understand land use, development, and aviation noise around airports.

FAA also supports research efforts at the Department of Transportation's Volpe National Transportation Systems Center. The Volpe Center provides research and support for the Integrated Noise Model, which airports use to model aviation noise at airports. Noise mitigation measures, such as residential soundproofing, are based on the noise contour maps generated by this model. The Volpe Center also conducts noise modeling studies. For example, it has conducted studies of aviation noise over the Grand Canyon in Arizona and over Bryce Canyon in Utah. FAA also has contracts with other entities such as Wyle Labs and Aerodyne Research to improve noise

¹⁵Transport Canada is the department within the government of Canada that is responsible for developing policies, regulations, and services for the Canadian transportation system.

¹⁶John-Paul Clarke, et al., Partnership for Air Transportation and Emissions Reduction Development, *Design and Flight Test Evaluation of a Continuous Descent Approach Procedure for Nighttime Operation at Louisville International Airport* (Cambridge, MA: Jan. 9, 2006).

measurement through modeling. For example, Wyle Labs performs work on the Model for Assessing Global Exposure to the Noise of Transport Aircraft, which estimates the global population exposed to noise and the effects of different mitigation scenarios. During the last decade, FAA has spent about \$43 million to support aviation noise R&D (see table 2).

Table 2: FAA Funds for R&D Efforts in Fiscal Years 1997-2007

Fiscal Year	Volpe Center	PARTNER	Other
1997	\$770,000		\$1,121,150
1998	841,000		1,654,000
1999	737,500		473,817
2000	1,040,000		577,000
2001	1,100,000		430,000
2002	889,000		869,000
2003	1,560,000	\$1,775,000	1,002,000
2004	1,231,000	1,200,000	1,740,000
2005	1,962,750	1,651,250	3,134,527
2006	2,349,750	3,378,657	2,875,750
2007	2,432,750	3,361,500	2,819,859
Total	\$14,913,750	\$11,366,407	\$16,697,103

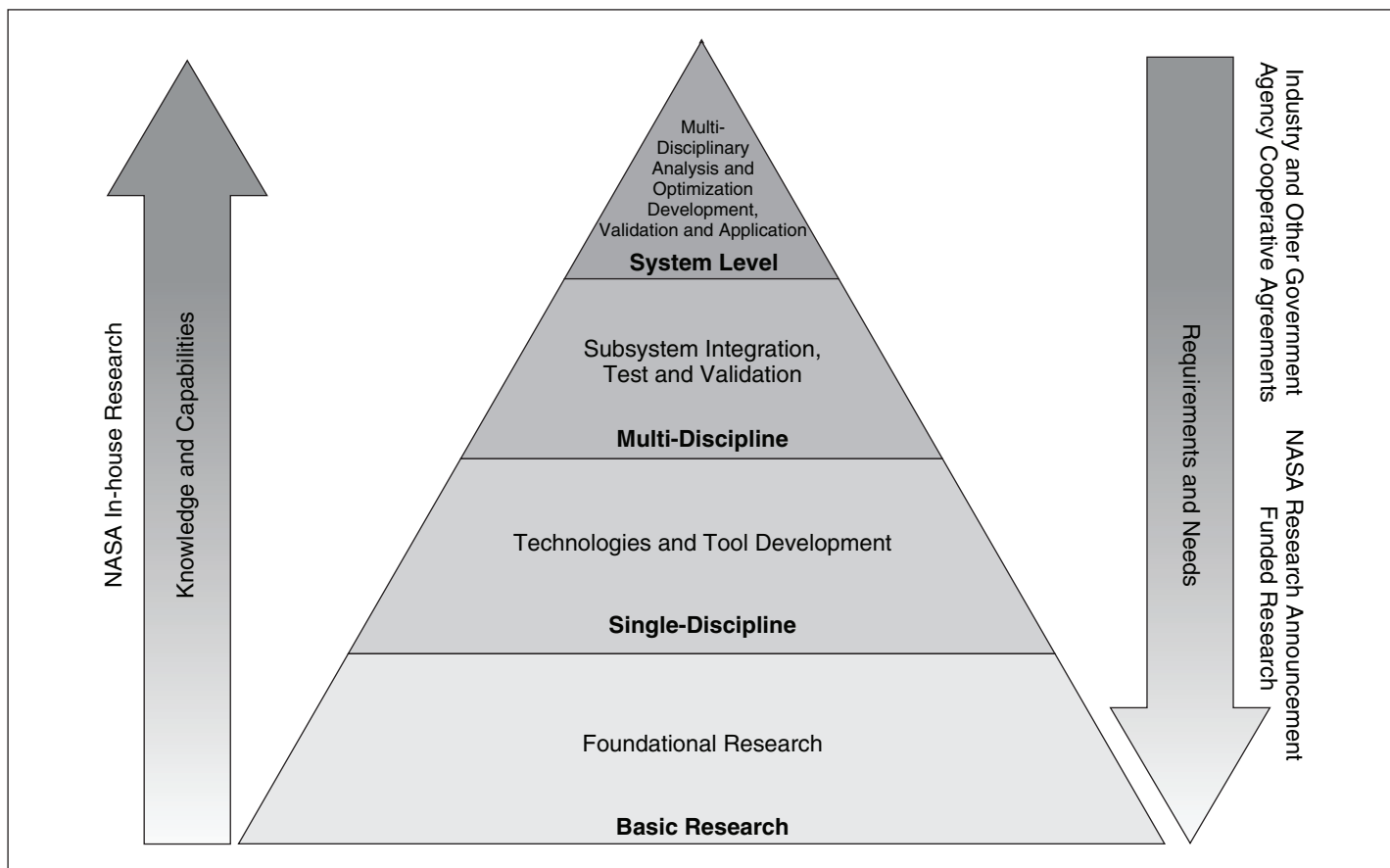
Source: FAA.

NASA's R&D Efforts Focus on Reducing Noise from Aircraft Engines and Airframes

NASA's efforts in the area of aviation noise are part of its overall aeronautical R&D program. NASA reorganized its aeronautical research plan in 2005 to focus on what it calls "fundamental research," which takes a technology to a point where it can be further matured by manufacturers and eventually integrated into new aircraft or engine designs. According to NASA, fundamental research includes (1) foundational research, which is the lowest level of the research pyramid on which advanced noise reduction technologies can be built; (2) discipline-level fundamental research, which includes the development of noise prediction methods that can be used to understand the noise reduction potential of various concepts; (3) multidiscipline-level fundamental research, which includes studying the trade-offs between noise, emissions, and performance that must be understood in order to determine the performance characteristics of a new aircraft; and (4) system-level fundamental research, which includes exploring research issues of interest to manufacturers when noise reduction technologies are integrated into a new aircraft and can include major wind-tunnel and flight tests. Figure 1 illustrates NASA's

research approach and shows that foundational research serves as the basis for the development of technologies and tools that can later be integrated into aviation subsystems and systems.

Figure 1: NASA’s Research Approach Triangle



Sources: GAO and NASA.

NASA’s research on aviation noise focuses on noise emitted by aircraft and emphasizes the development of noise prediction methods, diagnostic methods for determining noise sources, and noise reduction methods that are applicable across a range of aircraft. NASA’s R&D plan is structured around reducing noise from three generations of aircraft, or vehicles,

categorized as “N+1,”¹⁷ to be implemented by 2015; “N+2,” to be implemented between 2020 and 2025;¹⁸ and “N+3,” to be implemented between 2030 and 2035. N+1 R&D focuses on one of the main sources of aviation noise—aircraft engines—by addressing fan noise as well as parts of the airframe that produce noise, such as landing gear and flap sides. For the N+2 generation of aircraft, NASA intends to develop tools and technologies that more closely integrate the airframe with the propulsion system through such means as the blended wing body concept. This concept, which calls for mounting the engines above the wings, would allow the airframe to shield and thereby reduce the effects of engine noise. The N+3 generation of aircraft, according to NASA, will have further dramatic reductions in noise and emissions and improvements in performance. A request for proposal for N+3 is expected in the spring of 2008, with the objective of soliciting potential aircraft solutions and identifying key driving technologies for fundamental research investments. NASA states that noise reductions for N+2 and N+3 aircraft will depend strongly on the fundamental research that is carried out today. These NASA research efforts are also aimed at reducing emissions and fuel consumption, which in combination with noise reductions would help mitigate the environmental effects of future increases in air traffic.

NASA is also working with others in the aeronautics research community on other advanced designs, such as the “silent aircraft” concept that was created by researchers from Cambridge University in Great Britain and the Massachusetts Institute of Technology. According to NASA, about \$58 million of the fiscal year 2007 subsonic fixed-wing research budget was directed toward noise-related research.

In addition, NASA funds noise research conducted by outside organizations. According to NASA, it sponsors research by universities and companies for its Fundamental Aeronautics Program through NASA Research Announcements (NRA). NASA officials note that the agency has made 215 NRA awards ranging from \$100,000 a year to \$1.5 million a year since December 2007, and that many of these awards were directed toward noise generation, propagation, and mitigation.

¹⁷“N” refers to the current generation of tube-and-wing aircraft entering into service in 2008 such as the Boeing 787.

¹⁸According to NASA estimates, the introduction of N+2 vehicles for Initial Operational Capability for military or cargo vehicles would be around 2020, and Entry Into Service for commercial vehicles would be around 2025.

Participation in Advisory, Planning, and Coordinating Bodies Helps FAA and NASA Align and Monitor Their Aviation Noise R&D Plans

FAA and NASA have taken advantage of a number of mechanisms to align their aviation noise R&D plans. According to officials from both agencies, their collaboration in PARTNER is one of the ways they align their aviation noise R&D activities. Both FAA and NASA are members of the advisory board for PARTNER, along with representatives from aerospace manufacturers; airlines; airports; national, state, and local governments; professional associations; and community groups. The advisory board participates in strategic planning for PARTNER and semiannual reviews of the center's research plan to ensure, among other things, that the plan addresses national and international issues, including those related to aviation noise.

FAA and NASA also seek to align their aviation noise research plans through participation in formal reviews of each other's aviation noise research efforts. FAA representatives participate on NASA review panels to assess the technical quality, performance, and relevance of NASA research programs. In return, NASA participates in FAA's REDAC, which is responsible for coordinating FAA's research, engineering, and development activities with those of industry and other government agencies. REDAC was established in 1989 to advise the FAA Administrator on R&D needs in air traffic services; airport technology; aircraft safety; human factors; and environmental issues, including aviation noise. NASA's Associate Administrator for Aeronautics Research is a member of REDAC, as are representatives from NASA's research programs in aeronautics who serve on the committee's subcommittees.¹⁹ FAA's Director of the Office of Aviation Research is currently the Executive Director of REDAC.

Another key component of FAA's and NASA's efforts to align their aviation noise R&D plans, according to officials from both agencies, is their participation in JPDO's planning for NextGen. Both agencies are members of JPDO's Environmental Working Group,²⁰ which is headed by the FAA Director of the Office of Environment and Energy. NASA chairs the Environmental Working Group's Technology Standing Committee, which focuses on the development of technologies to lessen NextGen's environmental impacts.

¹⁹The four NASA aeronautics research programs are the Fundamental Aeronautics Program, the Airspace Systems Program, the Aviation Safety Program, and the Aeronautics Test Program.

²⁰JPDO has restructured its Integrated Product Teams into Working Groups. Nevertheless, FAA and NASA continue to collaborate in the same roles and according to the Integrated Work Plan.

According to FAA and NASA officials, the mechanisms in place to align their agencies' aviation noise R&D plans enable the two agencies and other stakeholders to periodically assess the potential for synergies or gaps in the agencies' research activities. FAA's and NASA's aviation noise plans focus on different aspects of aviation noise. As we have previously noted, most of FAA's R&D activities are presently concentrated on measuring and mitigating the impacts of aviation noise, whereas NASA's R&D centers on developing technologies to reduce noise from aircraft engines and airframes. Both agencies' participation in JPDO's Environmental Working Group and in REDAC and FAA's participation in NASA program reviews create opportunities for FAA and NASA to determine what adjustments in aviation noise R&D are needed to meet goals for reducing or mitigating the impacts of aviation noise. For example, the Environmental Working Group's analysis determined that more near-term demonstration of noise reduction technologies on aircraft was needed. According to FAA, the CLEEN proposal in the administration's reauthorization bill, which will be discussed later in this report, addresses this gap.

The extent to which FAA's and NASA's aviation noise R&D plans are aligned is indicated in JPDO's strategic plans for NextGen, which serve as a blueprint for improving the nation's aviation system. These plans show how each agency's R&D efforts will contribute toward meeting goals for reducing noise. Meeting these goals is critical for the success of NextGen because aviation noise is a major impediment to increasing the capacity of the NAS. JPDO's goal is to reduce the impacts of significant aviation noise (defined as DNL 65 dB) on communities despite the predicted growth in air traffic. Specifically, the Technology Standing Committee of the Environmental Working Group seeks to ensure the development of technologies to contribute to reducing the impact of aviation noise on communities. According to NASA, the technologies it is developing under its current aviation noise R&D program, if implemented in new generations of aircraft, would significantly contribute toward meeting this goal.

The alignment of FAA's and NASA's aviation noise research plans is also reflected in the national aeronautics research plan issued by OSTP in

December 2007.²¹ This plan, to which FAA and NASA contributed, outlines environmental goals that are aligned with JPDO's. In line with the JPDO Environmental Working Group's goal, the national plan states that the "environmental footprint of aviation must continue to shrink, even while accounting for an anticipated two to three times growth in capacity of the U.S. aviation system by 2025." The national plan includes FAA and NASA goals for aviation noise research. For example, the plan's near-term goals include researching and developing air traffic control procedures to reduce noise and developing improved tools and metrics to quantify and characterize aviation's environmental impacts. Long-term goals include developing new approaches and models for optimizing ground and air operational procedures. In addition, the technologies under development or planned for NASA's N+1, N+2, and N+3 programs are included in the national plan.

FAA and NASA have formalized their efforts to align their aviation noise R&D plans through memorandums of understanding (MOU) on R&D since October 9, 1998, with the latest dated May 2006.²² The most recent MOU describes how the agencies will coordinate their R&D efforts through the FAA/NASA Executive Research Steering Committee, which is co-chaired by the agencies, with selected members from FAA and NASA offices involved with research programs. According to the MOU, this committee ensures that complementary aviation and space transportation goals are defined for FAA and NASA and reflect each agency's mission. The MOU further states that the two agencies will acknowledge and support their goals, coordinate their planning and resources to achieve the goals when appropriate, and monitor progress toward the goals and propose changes on the basis of changing requirements.

²¹OSTP's charter is to advise the President on the effects of science and technology on domestic and international affairs and to lead interagency efforts to develop and implement science and technology policies and budgets. OSTP's plan, *National Plan for Aeronautics Research and Development and Related Infrastructure* by the National Science and Technology Council (December 2007), establishes national research priorities, objectives, and schedules to achieve the identified objectives by 2020.

²²*Memorandum of Understanding Between Department of Transportation, Federal Aviation Administration and National Aeronautics and Space Administration Concerning A Partnership to Achieve Goals in Aviation and Space Transportation* (May 15, 2006).

FAA and NASA Have Established Noise Reduction Technology Goals, but R&D Funding Issues and Other Factors Make the Achievement of Noise Reduction Goals Uncertain

FAA has established a goal for reducing the number of people exposed to significant noise from aircraft, while FAA and NASA have set goals for reducing noise from aircraft through technology development. However, questions about the sufficiency of federal funding for these efforts, the extent of government and industry participation in the later-stage development of noise reduction technologies, and airlines' ability to incorporate the technologies in the near term make the achievement of FAA's and NASA's noise goals uncertain. Failing to achieve these goals could stall the implementation of NextGen, because continued noise problems at airports could constrain its expansion.

FAA and NASA Have Set Goals for Reducing Aviation Noise through New Technologies

FAA has established a target for reducing the number of people exposed to significant noise from aircraft, while FAA and NASA have set targets for noise reductions in aircraft to be achieved through technology development. FAA estimates that about 500,000 people in the United States are currently affected by significant aviation noise, defined as DNL 65 dB or greater, and has set a goal of reducing this number by 4 percent for each year through fiscal year 2012. The annual 4 percent reduction goal is an increase over FAA's previous goal of an annual 1 percent reduction in the population exposed to significant aviation noise. According to FAA, the 1 percent goal was exceeded in fiscal year 2006 when the percentage of people exposed to significant noise decreased by 28 percent relative to the 3-year average for calendar years 2000 through 2002. FAA stated that the main contributor to the decrease in population exposed to significant noise is the early retirement of older, noisier aircraft primarily as the result of the air traffic downturn in the aftermath of the events of September 11, 2001, and fuel inefficiency reasons.

FAA has also set a goal that would more directly indicate the contribution of R&D to reducing aviation noise. FAA's 2007 National Aviation Research Plan qualitatively spells out R&D goals up to 2015. According to this plan, FAA's goal is to demonstrate that aviation noise can be significantly reduced to cost-effectively expand up to three times the current capacity of the air traffic system. FAA R&D activities from 2009 through 2013 to achieve these goals include (1) measuring current levels of aviation-related noise and emissions, (2) determining acceptable levels of noise and emissions, (3) developing models to predict the impact and benefits of changes, and (4) developing noise- and emission-reduction methods.

Current activities are being conducted by PARTNER and the Volpe Center in collaboration with various industry stakeholders.

NASA has established what it considers to be aggressive technology goals for its aviation noise R&D program that could be incorporated into aircraft. Under these goals, new technologies would be developed and incorporated in three succeeding generations of new aircraft, as we discussed in the preceding section of this report, thereby increasingly reducing what is known as EPN. NASA's goals include a cumulative noise reduction of 32 EPN dB relative to the most current Chapter 4 noise standard²³ for the next generation of aircraft, the N+1 generation,²⁴ and this goal would be achieved by 2015. Next, noise from the N+2 generation of aircraft would be reduced to 42 EPN dB below the Chapter 4 standard, and this goal would be met between 2020 and 2025. Finally, noise from the N+3 generation of aircraft would decline to 71 EPN dB below the Chapter 4 standard during the period from about 2030 through 2035, thereby achieving NASA's third noise reduction goal. Aviation noise would be reduced to the extent NASA predicts through the technologies it is researching if noise reduction were the only goal. However, when efforts are also made to achieve other goals, such as to reduce greenhouse gas emissions, noise reductions may be lower. FAA and the other members of JPDO's Environmental Working Group have incorporated NASA's aviation noise reduction goals in NextGen plans for reducing the environmental impacts of aviation. Table 3 identifies the time frames, goals, and research projects planned for NASA's N+X generation aircraft program.

²³In July, 2005, FAA issued a Federal Aviation Regulation (14 CFR 36.103 and 91.801-91.877) requiring that all new aircraft designs be subject to the current, more stringent ICAO noise standards, known as Chapter 4 (known as Stage 4 standards in the regulation). Specifically, any new aircraft whose design was submitted to FAA for approval on or after January 1, 2006, must meet these standards adopted by ICAO in 2001. The less stringent Chapter 3 standard applies to most other aircraft. Under the Chapter 4 standards, none of an aircraft's maximum noise levels at takeoff, landing, and approach can exceed Chapter 3 noise levels. Compliance with the standards is determined by subtracting an aircraft's maximum noise levels at takeoff, flyover, and approach from the maximum permitted noise levels. The differences obtained are the noise limit margins. When the three margins are added together, the total must be 10 EPN dB or greater; and when any of the two margins are added together, the sum must be 2 EPN dB or greater.

²⁴The reductions would occur in aircraft that would replace such current aircraft as the Boeing 737 and Airbus A320. Reductions would be different for larger aircraft and regional jets.

Table 3: NASA's N+X Generation Aircraft Program

Program name	N+1 generation	N+2 generation	N+3 generation
Time frame	By 2015	Between 2020 and 2025	Between 2030 and 2035
Noise level ^a	-32 EPN dB	-42 EPN dB	-71 EPN dB or greater
Research projects	Engine noise reduction technologies Airframe noise source Investigation and mitigation study	SAX-40 aircraft concept Aerodynamics and acoustic testing Predictive capabilities for subsonic aircraft Pulsed circulation control Plasma actuators for landing gear and high-lift side edges	NASA to solicit proposals in spring 2008

Sources: GAO and NASA.

^aCumulative reduction below Chapter 4 standards.

Meeting Noise Reduction Goals Is Uncertain Because of Questions about Federal R&D Funding, Government and Industry Participation, and Airline Investment Resources

Despite efforts by FAA and NASA, to align aviation noise and other environmentally related R&D, concerns have arisen about whether the resources devoted to near-term R&D will be sufficient to achieve noise reduction goals for aircraft engines and airframes within the NextGen time frame. According to FAA, more funding is needed to mature noise reduction technologies beyond NASA's research efforts. FAA is attempting to address this funding need through its proposed CLEEN consortium.

Federal funding for aviation noise research has declined over the past decade, particularly for NASA, which provides most of the federal funding for aeronautics research, the category that includes aviation noise research. NASA's budget for aeronautics research has dropped by about one-half over the past decade and is about \$717 million for fiscal year 2007. According to NASA, about \$58 million of this funding goes toward noise-related research for subsonic fixed-wing aircraft. This downward trend contributed to NASA's decision, previously discussed in this report, to refocus its aeronautical research plan on the earlier stages of the R&D process.

According to FAA, most of the federal funding available for mitigating aviation noise is targeted to the Part 150 Noise Compatibility Program for soundproofing buildings around airports and acquiring or relocating properties that are exposed to high levels of aviation noise. In a 2002 report on reducing the environmental impacts of aviation, the National

Research Council's Committee on Aeronautics Research and Technology for Environmental Compatibility²⁵ noted that the vast majority of federal expenditures on aviation noise is allocated to noise abatement at individual airports rather than to research on quieter aircraft and engines, which could ultimately lead to reductions in aviation noise nationally and internationally. The report concluded that the funding for federal research programs was too low to remove noise as an impediment to the growth of aviation—a conclusion that FAA reiterated in a 2004 report to Congress on aviation and the environment.²⁶

According to FAA, the administration is attempting to address the shortfall in aviation noise R&D spending in its proposal for reauthorizing FAA programs by seeking funding for programs to mature technologies that NASA and others originally developed. FAA officials stated that the proposed CLEEN Engine and Airframe Technology Partnership, for which the administration is seeking \$111 million through fiscal year 2011, is intended to provide earlier maturation of aviation noise and emission reduction technologies while NASA focuses on longer-term fundamental research on noise and emissions. The CLEEN partnership, which is also in the House reauthorization bill, would create a program for the development, maturation, and certification of engine and airframe technologies for aircraft over the next 10 years to reduce aviation noise and emissions. The proposals would require the FAA Administrator to establish an objective of developing aircraft technology that would be certified for incorporation into current aircraft models, resulting in a cumulative noise reduction of 32 EPN dB below ICAO's Chapter 4 standards, which is the same as the goal NASA has set for its N+1 aviation noise R&D program. CLEEN would establish a research consortium of government, industry, and academic participants that would allow for the maturation of aviation noise technologies via demonstration projects for further refinement by the aviation industry and eventual incorporation into new aircraft designs. The proposal would also require the Administrator to set objectives for developing certifiable aircraft engine technologies for substantially reducing emissions. Because NASA's current focus is on fundamental research to develop system-level technologies, the CLEEN proposal would not overlap with NASA's R&D efforts. According to FAA, if

²⁵National Research Council, Committee on Aeronautics Research and Technology for Environmental Compatibility, National Academy of Sciences *For Greener Skies: Reducing Environmental Impacts of Aviation* (Washington, D.C.: 2002).

²⁶FAA, *Aviation and the Environment: A National Vision Statement, Framework for Goals and Recommended Actions* (Washington, D.C.: December 2004).

the proposed program is authorized and funded at the requested level, FAA has reasonable confidence that noise goals will be achieved.

NASA and FAA officials said they are making progress in meeting their noise reduction goals. NASA officials stated that NASA is progressing toward developing technologies that can be implemented in next generation aircraft engines and can meet the noise reduction goals set for N+1. For example, NASA has established a partnership with Pratt & Whitney to demonstrate the benefits of a technology that would reduce noise. NASA and FAA have also worked with Boeing to demonstrate airframe and engine noise reduction technologies on a Boeing 777. FAA stated, and we have confirmed, that FAA has met its 2007 noise reduction goals through September 2007.

However, even with additional funding for aviation noise R&D, such as the amounts included in the CLEEN proposal, achieving FAA's and NASA's aviation noise goals for reducing noise from aircraft engines and airframes will remain a challenge because of uncertainties about the ability of aircraft engine and aircraft manufacturers to incorporate new noise reduction technologies into new engine and aircraft designs, and the need to consider trade-offs between noise reductions and reductions in emissions of greenhouse gases. NASA officials stressed that when NASA's research ends, it will be up to engine and aircraft manufacturers to take the next steps to integrate the noise reduction technologies into engine and aircraft designs, and the manufacturers' willingness to do so is not guaranteed. In addition, an expert we consulted noted that if manufacturers do take the steps to integrate noise reduction technologies into new designs, the pace of noise reduction will also depend on the pace of development for new aircraft and aircraft engine designs. According to FAA, the CLEEN proposal is to demonstrate to manufacturers that technologies initially developed by NASA and others are ready to be incorporated into new aircraft and engine designs. However, it is uncertain whether the CLEEN proposal, if adopted, would be sufficient to achieve this objective. Concern about other environmental problems, such as global warming and air quality, may also limit the likelihood of achieving FAA's and NASA's noise reduction goals, since it may be technologically challenging to design aircraft with reduced noise while, at the same time, achieving the significant reductions in greenhouse gases and other emissions that will be required. Although it is possible to design engines that produce less noise and fewer greenhouse gas emissions, the reductions in greenhouse gases could be limited in engines that produce substantially less noise. Furthermore, engines that burn less fuel are less costly to operate. As a result, air carriers may not be inclined to buy jets with engines that reduce noise but may be more expensive to operate.

If R&D efforts lead to advancements in noise reduction technologies that can be incorporated in new aircraft in the near future, it is uncertain whether these advancements will contribute toward meeting FAA's goals for reducing the number of people exposed to significant noise. As we noted in our recent testimony on aviation noise,²⁷ implementing new noise reduction technologies, whether by integrating new, quieter aircraft into the fleet or by retrofitting aircraft, poses financial challenges for the aviation industry. Aircraft have an average lifespan of about 30 years, and airlines can take almost that entire period to pay for an aircraft. The current fleet is, on average, about half as many years old—11 years for wide-body aircraft and 14 years for narrow-body aircraft—and therefore, is expected to be in operation for many years to come. In addition, the financial pressures facing many airlines make it difficult for them to upgrade their fleets with new, state-of-the-art quieter aircraft, such as the Boeing 787 and Airbus A380. Currently, for example, U.S. carriers have placed a small proportion of the over 700 orders (40, or less than 6 percent) that Boeing officials say the company has received for its 787 model. Furthermore, no U.S. carriers have placed orders for the new Airbus A380, which is the world's largest passenger aircraft. According to Airbus, the A380 produces significantly less noise than other large passenger aircraft currently in service.

Failure to meet the aviation noise reduction goals outlined in FAA's and NASA's R&D plans could have significant implications for the implementation of NextGen. According to FAA, it generally takes 12 to 15 years to implement new technology on aircraft, and, therefore, NextGen technologies must be brought to maturity soon to meet the 2025 goal for implementing NextGen. According to FAA, without additional funding such as that proposed for CLEEN, near-term noise reduction goals may not be attained. However, if the technologies are developed that allow the goals to be met, FAA may also need to consider how to encourage airlines to introduce quieter aircraft into their fleets as well as to retrofit existing aircraft with new equipment such as the satellite-based Automatic Dependent Surveillance-Broadcast (ADS-B) navigational system, which can allow aircraft to make more efficient, quieter approaches and descents. One way would be to offer operational advantages such as preferred takeoff and landing slots to quieter aircraft or aircraft equipped with ADS-B. Without significant noise reductions around the nation's airports, efforts to expand their capacity could be stalled and the

²⁷[GAO-08-216T](#).

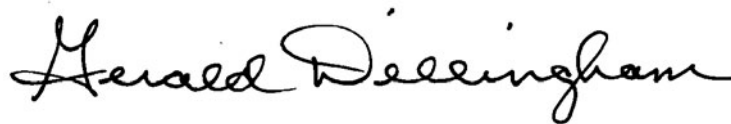
implementation of NextGen delayed, thereby limiting FAA's ability to efficiently manage the forecasted growth in air traffic.

Agency Comments

We provided copies of a draft of this report to the Department of Transportation and NASA for review and comment (see app. II). Both agencies had no comments. FAA and NASA did provide technical clarifications, which we incorporated into the report as appropriate.

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

If you or your staffs have any questions about this report, please contact me at (202) 512-2834 or dillingham@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. Individuals making key contributions to this report are listed in appendix III.



Gerald L. Dillingham, Ph.D.
Director, Physical Infrastructure Issues

Appendix I: PARTNER Participants and Projects

Collaborating Universities

Boise State University
Georgia Institute of Technology
Harvard University
Massachusetts Institute of Technology
Pennsylvania State University
Purdue University
Stanford University
University of Missouri at Rolla
University of North Carolina
York University

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FAA Airport Planning, Community and Environmental Needs Division
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FAA Flight Standards
FAA Office of Environment and Energy
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Gulfstream Aerospace
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Indiana Department of Transportation
International Airline Passengers Association
Larry Finegold & Son, Consultants
Lockheed Martin Aeronautics

Logistics Management Institute
Massachusetts Port Authority
Metron Aviation
Metropolitan Washington Airport Authority
NASA Aeronautics Research Mission Directorate
NASA Science Mission Directorate
National Organization to Insure a Sound Controlled Environment
O'Hare Noise Compatibility Commission
Omega
Palisades Citizens Association
Pratt & Whitney
Raisbeck Engineering
Rannoch Corp.
Regional Airport Authority of Louisville and Jefferson County
Rolls Royce
San Francisco International Airport/Community Roundtable
Sikorsky Aircraft
SNECMA
Transport Canada
United Parcel Service
U.S. DOT Volpe National Transportation Systems Center
U.S. EPA National Risk Management Research Laboratory
Wyle Laboratories

PARTNER Projects

Airport Surface Movement Optimization
Alternative Fuels
Continuous Descent Arrival
En Route Traffic Optimization to Reduce Environmental Impact
Emissions Atmospheric Research
Emissions Characteristics of Alternative Aviation Fuels
Energy Policy Act Study
Environmental Design Space
Health Effects of Aircraft Noise
Health Impacts of Aviation-Related Air Pollutants
Investigation of Aviation Emissions Air Quality Impacts
Land Use Management and Airport Controls (project completed)
Lateral Alignment in Complex Systems (project completed)
Low Frequency Noise Study (project completed)
Measurement of Emissions
Network Restructuring Scenarios for ATO Forecasts
NoiseQuest

**Appendix I: PARTNER Participants and
Projects**

Quantifying and Mitigating the Impact of Noise on People
Reduced Vertical Separation Minimums (project completed)
Sonic Boom Mitigation
Valuation and Trade-offs of Policy Options

Appendix II: NASA Letter to GAO

National Aeronautics and Space Administration
Headquarters
Washington, DC 20546-0001



February 5, 2008

Reply to Attn of: Aeronautics Research Mission Directorate

Gerald L. Dillingham, Ph. D.
Director, Physical Infrastructure Issues
Government Accountability Office
Washington, DC 20548

Dear Dr. Dillingham:

Thank you for the opportunity to review your draft report entitled, "Aviation and the Environment," (GAO-08-384). This draft report contains no recommendation to NASA and we are not providing comments via separate correspondence.

If you have any questions, or require additional information, please contact Juan Alonso at (202) 358-1216.

Sincerely,

A handwritten signature in black ink, appearing to read "Jaiwon Shin".

Dr. Jaiwon Shin
Associate Administrator for
Aeronautics Research

Appendix III: GAO Contact and Staff Acknowledgments

GAO Contact

Gerald L. Dillingham, Ph.D., (202) 512-2834 or dillinghamg@gao.gov

Staff Acknowledgments

In addition to the contact named above, Ed Laughlin (Assistant Director), Elizabeth Eisenstadt, Rosa Leung, and Maureen Luna-Long made key contributions to this report.

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