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Critical Issues in Aviation and the Environment

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Critical Issues in Aviation and the Environment

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Contents

Introduction

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BACKGROUND

From the beginnings of powered flight over a century ago, the potential impact of aviation on the natural and human environment has been recognized, if often poorly understood. The development of airfields and airports in this country required terrain that is level and free of natural obstructions in the vicinity, and these facilities must be easily accessible to cities and towns, which in turn are situated often near rivers, lakes, and oceans. Because of these factors, airports have tended to develop on large, flat sites in proximity to major bodies of water; sites that typically support diverse and complex natural systems vulnerable to disturbance. Development of airports also has affected the social environment and vice versa. Airports originally constructed far from town often become embedded within the metropolitan areas that have grown up around them, bringing areas where large numbers of people live and work much closer to the airport fence than the planners of either the airports or the cities anticipated. Moreover, as awareness of the global environment evolves, more attention is being paid to the potential environmental impact of aircraft operating at altitude as well as within airport environs. Today, aviation traffic is an important and growing mode of transport, the environment has become increasingly stressed from a variety of sources, the population is expanding, and the connections among these elements have become increasingly complex and difficult to manage efficiently and equitably. Research on ways to assess and ameliorate these conditions is underway and promises substantial benefits. A future in which aviation exists in harmony with the natural and human environment is possible, but cannot occur without better knowledge and understanding of existing and future environmental impacts and the opportunities for mitigating or avoiding them.

OVERVIEW

The Transportation Research Board (TRB) Environmental Impacts of Aviation Committee (AV030) issues this first annual summary of critical issues in aviation and the environment in the United States with the goal of identifying priority research that can yield potential benefits during a period that spans the next several years to several decades. The value of the summary is intended to be its cross-disciplinary review of topics of interest to airports and other elements of the aviation community, with the focus on the state of science rather than on policy. The summary comprises six sections, three that address the major environmental media affected by aviation activities (noise, air quality, and water) and three that address key processes that link aviation and the environment (analytical tools, environmental review processes, and technology deployment). The first five sections are divided into subsections that

- Define the critical issues in the media or process area;
- Discuss the current state of practice, research, and policy;
- Define a vision of future capabilities that would address the critical issues; and
- Identify specific research needs to help achieve the vision.

The final section includes only the first subsection—critical issues that face the deployment of technology. The remaining portions of this topic area will be developed further by this committee either as a separate paper or in subsequent versions of this paper. Each section focuses on research conducted in the United States, although international activities are discussed where U.S. public or private entities are closely involved. A variety of published and unpublished material, public information, and individual contributions were collected to prepare this paper. Future versions will highlight the key references in each topic area.

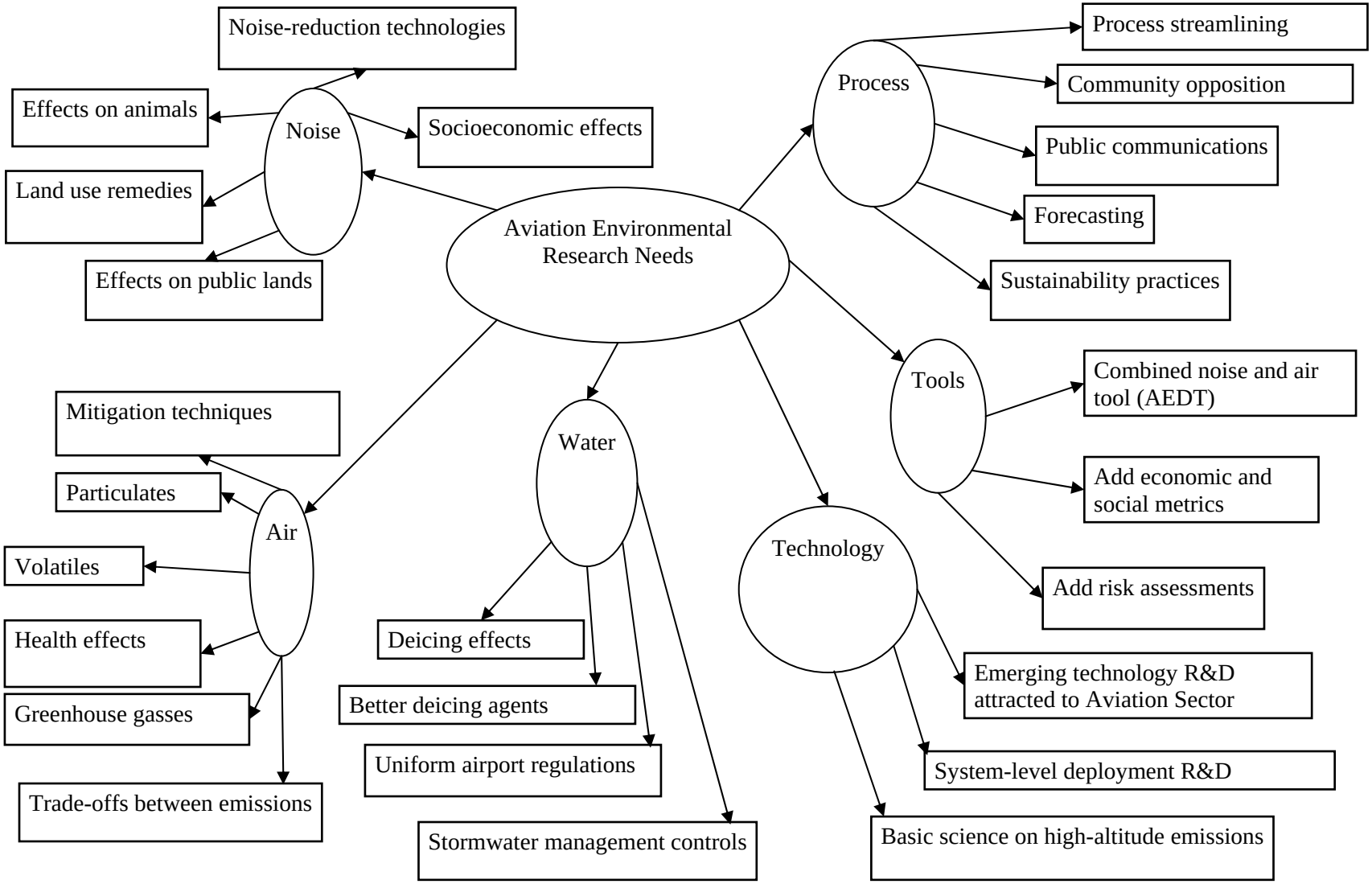
Figure 1 (page 3) provides an overview of the research needs considered in this review.

Because of constraints on time and effort, the "Critical Issues" portions of each section do not claim to address all potentially critical issues in a given field. For example, the paper does not fully address climate change, which is a critical emerging environmental issue to which the aviation community must devote more research in order to more clearly understand the aviation–environment relationships. Neither does it address comprehensively land use development near airports, which represents a major constraint on future aviation activity and for which effective controls need to be developed. Sustainable development, threatened and endangered species, and other topics are critical issues that also are not addressed but may be added in future papers. The critical issues listed here have varied and evolved over time and will continue to do so. For example, while aircraft noise impacts were once pre-eminent among the operational environmental issues associated with aviation, air quality concerns have now achieved nearly equivalent status. Water quality issues now seem likely to assume the same sort of importance that special status species and wetlands impacts have long held.

The "Current State" portion of each of the paper's sections addresses efforts now under way in the broad community of professionals concerned with aviation and the environment to advance the resolution of the issues. To this end, TRB maintains a number of committees and task forces that focus on specific environmental topics (e.g., noise and air quality), as well as committees concerned with various aspects of aviation, which is the TRB Technical Activities Group to which the Environmental Impacts of Aviation Committee belongs. The committee coordinates with all of the other committees in the planning of meetings, Annual Meeting sessions, paper reviews, and similar matters. The "Current State" portions of the paper help to further one of the goals of the Environmental Impacts of Aviation Committee—to integrate the work of other TRB committees, along with research produced in the various sectors of the aviation community, into a summary document focused on research addressing the environmental impacts of aviation.

The "Future Vision" portions of the paper sections reflect current public policy and are intended to be descriptive rather than prescriptive. In December 2003, Congress approved the Federal Aviation Administration (FAA) reauthorization bill ("Vision 100"). FAA reauthorization includes extensive environmental provisions designed to streamline environmental review processes and to mitigate aviation's environmental impacts with a number of noise and air quality initiatives, thus directly addressing what are typically the most significant aviation environmental impacts. For example, the reauthorization establishes a new voluntary program to reduce airport ground emissions at commercial service airports in air quality nonattainment and maintenance areas and makes more flexible use of the Airport Improvement Program noise set-aside to fund this program. The noise set-aside has been funded at a higher level to support emission projects and to fund grants to state and local governments to enhance the compatibility of land uses adjacent to large and medium-sized airports. There is also added

FIGURE 1 Aviation Environmental Research Agenda Overview Map



flexibility in the use of the noise set-aside to fund the mitigation of noise impacts of airport expansion. The reauthorization provides for streamlined environmental review processes for airport capacity projects, aviation safety projects and aviation security projects.

"Research Needs" set forth in the paper's sections also reflect provisions in the FAA reauthorization, which includes the authority to establish an Airports Cooperative Research Program (ACRP). The purpose of ACRP, which is based in part on the cooperative research programs in transit and highways, is to fund research projects identified by airports as having high priority, clearly defined objectives, and immediate practical applications. Among the types of research projects enumerated in the National Research Council report recommending establishment of the ACRP are several that are environmental in nature, and it is expected that proposals addressing environmental topics will be among those eligible for funding in the first funding year (2005). The paper's sections draw from these recommendations and, in turn, may provide useful inputs into the program's future research decisions.

ACKNOWLEDGMENTS

This summary represents the viewpoints of the authors and reviewers of the individual papers. The sections comprising the summary were reviewed by a number of the members and friends of the Environmental Impacts of Aviation Committee, including

- Richard Burke (lead reviewer), Kennedy/Jenks Consultants;
- Christine Gerencher, American Airlines;
- Lourdes Maurice, Federal Aviation Administration;
- Anthony D. Perl, University of Calgary, Canada;
- Darcy Zarubiak, Dallas–Fort Worth International Airport;
- Ed Melisky, Federal Aviation Administration; and
- Carl Burleson, Federal Aviation Administration.

The TRB Environmental Impacts of Aviation Committee plans to update this summary annually. Comments on the summary or on individual papers, or on both, are welcomed by the Committee and should be addressed to

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Noise

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CRITICAL ISSUES

Aircraft noise historically has been one of the major constraints to increasing civil aviation capacity. Despite the facts that community exposure to aircraft noise has decreased markedly over the last several decades and that the National Aeronautics and Space Administration (NASA) has ambitious technology goals for the future, expectations of continued decreases in noise levels may not reflect the reality of the extended time frame required for development and adoption of advanced technology for the next generation of quieter aircraft.

CURRENT STATE

Several efforts are under way to address the problem of aircraft noise by designing aircraft that generate less noise. Other research efforts have focused on operating aircraft to reduce noise impacts and on planning airports and surrounding communities to avoid exposing sensitive land uses like homes and schools to aircraft noise. Aviation noise research in the United States is conducted in a number of different institutional settings, including federal and state governments, universities, and private consulting firms. Federal agencies coordinate research priorities and findings through the Federal Interagency Committee on Aviation Noise (FICAN, see www.fican.org). FICAN members include the Department of Transportation, Department of Defense (DoD), Environmental Protection Agency (EPA), NASA, Department of Housing and Urban Development, and Department of the Interior. Research undertaken by these agencies includes the following:

- NASA's Quiet Aircraft Technology Program is undertaking research on ways to remove noise as a constraint on air transportation. Its vision is to contain noise within the airport boundary. NASA has identified a 10-year goal of containing airport noise measured in terms of a Day-Night Noise Level (DNL) of 65 dB or greater within the airport boundary and a 25-year goal of containing DNL 55 dB or greater within the airport boundary.
- DoD coordinates research across the services through its Unified Airborne Noise Program. The goals of the DoD working group include (1) development of a Strategic Environmental Noise Research Plan coordinated through the Services and (2) establishment of a Defense Environmental Noise Working Group to staff and prioritize the issues. The Program will address requirements and funding priorities across the mainstream of DoD airborne noise issues including models, data acquisition, and research and development.
- DoD has been the primary agency funding research on aviation noise effects on animals, including recent studies on Mexican spotted owls, red-cockaded woodpeckers, marine mammals, and other aquatic animals. There has been some work to develop models for predicting aviation noise as it propagates through the air–water transition zone and under water.
- FAA and NASA have established an Air Transportation Center of Excellence for Aircraft Noise and Aviation Emissions Mitigation. This Center has identified an ambitious preliminary agenda, including two studies prescribed by Congress to address low-frequency

noise and to analyze continuous descent approaches. Longer-term research goals for the Center include the socio-economic effects of noise and noise mitigation, noise abatement flight procedures, compatible land use management, and airport operational controls.

- FAA has undertaken a survey to identify and evaluate innovative programs that employ land use controls to address community noise exposure. Certain states (e.g., Florida and California) also have adopted land use compatibility evaluation and planning processes for airports and their environs.
- FAA has initiated development of a new aircraft systems model that integrates engine and aircraft design with aircraft operations to examine environmental performance and technology development. TRB is assisting FAA in the development of the model by facilitating workshops and soliciting input from the aviation user, operations, manufacturing, and research communities on FAA's plan to develop an Aviation Environmental Design Tool (see Tools section below).
- FAA, in cooperation with the National Park Service, has the lead role in developing Air Tour Management Plans for national parks that are or are anticipated to become air tour destinations. The goal of these plans is to minimize the effects of aircraft noise in sensitive parklands.
- FAA has been working with the United Nations International Civil Aviation Organization (ICAO) on the development of noise standards for the next generation of civil aircraft. The Stage 4 noise standard adopted by ICAO requires newly manufactured aircraft to be at least 10 decibels quieter than Stage 3 aircraft. The Stage 4 standard, which takes effect on January 1, 2006, also includes provisions for recertifying existing aircraft to meet the more stringent standard.
- The Department of the Interior conducts research on the effects of aircraft overflights, watercraft, snow machines, ground transportation vehicles, and other sources of human-produced sounds on units of the National Park system. The lead agency for the Department is the National Park Service. As part of its efforts, the Service has issued Director's Order 47 to articulate its policies that require the protection, maintenance, or restoration of the natural soundscape resource in the national parks. This order directs park superintendents to use the National Park Service planning process to ensure the preservation or restoration of natural soundscapes.
- Currently, there is no noise research program at EPA or the Department of Housing and Urban Development.

A number of nongovernmental groups concerned with aviation have research programs or research agendas, including the following:

- The TRB Transportation-Related Noise and Vibration Committee (ADC40) prepared a list of research needs as part of the TRB Environmental Research Needs Conference in March 2002. The committee's research priorities include a cost–benefit analysis of transportation noise, development of a methodology for quantifying transportation noise exposure in the United States, an aircraft noise health effects study, aircraft community noise impact below 65 dB DNL, best practices for sound insulation around airports, technical tools to support land use compatibility planning, a synthesis of noise-effects on wildlife and development of impact assessment guidelines, a study of community response to nonaircraft transportation noise, and research on helicopter noise impacts to the community.

- The Society of Automotive Engineers, Aviation Noise Committee (SAE-A21) is tasked with developing standards and practices in the area of interior and exterior noise associated with aircraft and their environments. Research supporting this effort currently includes monitoring noise from aircraft operations in the vicinity of airports and application of pure-tone atmospheric absorption to one-third octave-band data.

FUTURE VISION

We need to develop advanced technologies that will further reduce aircraft noise and noise exposure. Since this effort will require time to develop and deploy, we need to better understand the relationship between aviation noise and community reaction, and we need to find ways to make aviation more compatible with nearby communities.

RESEARCH NEEDS

Research priorities for aviation noise fall into the following categories:

- Continue to improve long-term and short-term noise reduction technologies. Ongoing research in source noise reduction is focused on design elements as well as operational procedures. Long-term needs include new technologies to address engine, airframe, and structural noise. Shorter-term research needs include optimization of low-noise operational procedures (e.g., navigational-aided departures and approaches, noise abatement departure procedures); demonstrations and evaluations of low noise operational procedures and their impact on capacity; assessment of the effectiveness of the aircraft noise certification demonstration procedures in promoting low noise designs for modern aircraft; and investigation of new procedures taking noise and emissions reduction and associated capacity benefits from advances in airborne and ground technologies for communication, navigation, and surveillance.
- Examine the socioeconomic effects of noise on people. There are a number of issues that remain to be resolved through research, including examination of the explicit and implicit costs of aircraft noise; evaluations of the adequacy of the current noise metrics used in the assessment of noise impacts and development and application of supplemental noise metrics; examination of the relationship between human health and noise, including sleep and sleep disturbance effects, differing impacts of noise in different communities and settings (e.g., urban and rural), the difference between aircraft noise and ambient noise levels, and other human impacts; investigation of the effects of aircraft noise on children's ability to learn; and investigation of the trade-off between actions to reduce aircraft noise and the implications for pollutant emissions and particulate matter.
- Conduct further research on noise effects on animals. More work needs to be done in the area of hearing thresholds for various animal groups and the development of specific animal group "weightings." Traditionally, researchers have used A-weightings, C-weightings, and flat sound pressure levels, which are not appropriate for use in describing noise stimuli for animals. In recent years, researchers have developed "bird" weightings (e.g. "woodpecker" weightings, "owl" weightings). Further work in this area is needed. Another area of research needed is in cumulative effects on animals to address not only aviation noise but also the combined impact of other sources (auto traffic, industrial, pollution, human interactions, etc.).
- Expand research on noise and vibration effects on structures and land use compatibility. Most research has focused on sonic booms. Additional research is needed in the following areas: the effects of low frequency noise and vibration, evaluation of the effectiveness

of sound insulation in residences and schools, examination of the occurrence and prevention of population encroachment into incompatible land use areas, identification of best practices and techniques for long-term compatible land use protection around airports, and identification of best practices for sound insulation techniques.

- Continue to study effects of overflights on public lands. Research needs include refinement of existing noise models to adequately consider the unique technical issues posed by natural areas, definition of criteria for evaluating impacts on natural lands, and appropriate use of noise monitoring data in defining and assessing park soundscapes.
- Identify effective strategies to communicate information on noise. Additional research is needed to find the most effective ways to communicate to the public regarding airport noise. Good communication methods are needed to explain the basics of noise measurement, to make people aware of how to reduce impacts of the noise environment on their residences, and to alert prospective residents where noise-intrusive areas exist. Some airports have established better relationships with their neighbors through good noise communication, monitoring, and education programs. Further research is needed to help identify and disseminate these best practices.

Air Quality

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CRITICAL ISSUES

During the 1990s, air pollution associated with aviation and airport-related sources became a prominent issue facing many of the large air carrier and general aviation airports in the United States. Today, criteria pollutants [carbon monoxide (CO), nitrogen dioxide ($NO_{2)}$, ozone (O_3) and its precursors—oxides of nitrogen (NO_x) and volatile organic compounds (VOCs)—sulfur oxides (SO_x), and particulate matter (PM)] from airports account for less than 0.5% of total emissions in the United States (2003 General Accounting Office Report to Congress). Nevertheless, aviation sources, like those associated with other transport modes, can contribute to local air quality issues. For example, activity at a single large airport or at multiple airports in an area typically contributes up to five percentage points to an area's NO_x inventory. Such effects may present especially difficult problems for future aviation capacity growth as 41 of the 50 busiest airports in the United States are located in ozone nonattainment and maintenance areas. Also, unlike other stationary or mobile sources, emissions from aviation-related sources are expected to increase in the future as air travel increases.

Recent litigation concerning airport development includes claims that airport operations are significant sources of air toxics, also known as hazardous air pollutants (HAPs), and cause adverse health effects in adjacent communities. With currently available tools, HAPs coming from aircraft are difficult to distinguish from those coming from other combustion sources, such as ground transportation. To better understand the role that aviation sources may play in this local air quality issue, the state of the science regarding the measurement and dispersion of HAPs, and their associated health effects requires further advancement.

From a global perspective, the most prominent pollutants under investigation in the aviation community are those classified as greenhouse gas emissions, such as carbon dioxide (CO_2). As a result of the recommendations of the United Nations Framework Convention on Climate Change Kyoto Protocol to address greenhouse gas emissions, the International Civil Aviation Organization (ICAO) has been considering how international aviation might best pursue limits on or reduction of these emissions. Several means are continuing to be investigated at the international level, while individual countries (including the United States) try to address their own domestic policies on these emissions from the aviation sector.

CURRENT STATE

Aviation air pollution studies, including research, in the United States are conducted in a number of different institutional settings, including federal and state governments (predominantly in California), universities, and private consulting firms. The principal federal programs include

- TRB's report *Airport Research Needs—Cooperative Solution*, which ultimately led to a congressionally authorized Airport Cooperative Research Program in 2003, identifies air quality as an area of potential research.
- NASA, the U.S. federal agency responsible for aeronautic and atmospheric research, conducts research on the atmospheric effects of aviation in collaboration between the Earth Science Enterprise and the Aeronautical Enterprise. One of the key themes of the Aeronautical Enterprise is to "protect local environmental quality and the global climate by reducing aircraft noise and emissions." The primary NASA aeronautic research program to achieve these objectives is the Vehicle Systems Program. The Ultra-Efficient Engine Technology (UEET) Project under this program primarily concentrates on the development of advance aircraft and engine technology in reducing emissions from the aircraft with gas turbine engines, and the Low Emissions Alternative Power Project in reducing emissions with alternative engine power sources or fuels. Particle emissions and their atmospheric impact have been a research focus of the UEET Project. Major efforts include particle emissions measurement and sample technology development, engine and atmospheric modeling, and combustor and engine particle emissions measurements.
- FAA is working with other federal agencies, industry, academia, state organizations, and public interest groups to develop a National PM Roadmap. The genesis of this effort was an Aviation Particle Emissions Workshop held by the NASA UEET Project. Knowledge gaps and research needs were identified in the workshop, and a research roadmap was developed based on the recommendation of U.S. experts from government agencies, academia, professional organizations, and aviation industries. In January 2004, FAA convened the first of a number of meetings to begin building on past work to develop the National PM Roadmap.
- Based on UEET particle emissions research efforts, the UEET Project also put together a proposal called "Air Matters" to advance knowledge of impact associated with local, regional, and global aviation emissions to guide aviation technology development. FAA expressed its support and interest in partnering with NASA. The EPA is currently looking into this partnering opportunity. This activity would be one of the components of the National PM Roadmap.
- FAA is developing a strategic framework to address aviation emissions in response to a Government Accounting Office assessment of challenges posed by aircraft emissions.
- FAA conducted a review of literature on particulate matter emissions from aircraft and based on the findings developed a First-Order Approximation to predict the emission rate of particulate matter by mode and jet/gas turbine engine model. FAA is currently working to complete the final report on these efforts.
- FAA published a state-of-science report on HAPs coming from aircraft and airports during 2003. FAA is currently working on developing standardized guidelines for assessing and modeling HAPs at an airport. Follow-on work will develop guidance for assessing health risk from exposure to HAPs.
- The aviation community, including government agencies (FAA, EPA, and NASA), industry (manufacturers, airports, and airlines), academia, and professional organizations are

planning to continue and possibly augment efforts to develop better ways of measuring particulate matter and HAPs. For example, the aviation community is working with the Society of Automotive Engineers E31 subcommittee to develop methods for measuring PM for adoption by ICAO. In early 2004 the aviation community began the development of a national roadmap to address PM from aircraft sources. This activity would be one of the components of the National PM Roadmap.

- FAA has sponsored the development of tools to evaluate aviation-related emissions. The System for Assessing Aviation's Global Emissions provides the capability to evaluate various options for reducing aircraft fuel burn and emissions over the whole flight regime. The Emissions and Dispersion Modeling System is FAA's required model for assessing emissions from aviation sources in the vicinity of airports for purposes of demonstrating compliance with the Clean Air Act and National Environmental Policy Act, which address a portion of concerns raised by the public and agencies.
- Center of Excellence for Aircraft Noise and Aviation Emissions. FAA, in partnership with NASA and Transport Canada, has established an Air Transportation Center of Excellence for Aircraft Noise and Aviation Emissions Mitigation. The initial research priorities for this consortium focus on noise issues, but some efforts to address atmospheric and health effects of aviation emissions and interdependencies between noise and emissions are included. The investment in emissions projects also will grow to the same level as noise investments by Fiscal Year 2005. However, the overall level of funding is far below requirements.
- FAA has plans to develop integrated noise and emissions analyses and economic assessment tools (see Tools section below).
- FAA is establishing a grant-in-aid program to provide funding from the aviation trust fund for alternative fuel vehicles at airports, including vehicle fleet conversions and infrastructure needed to support such equipment.
- EPA has sponsored research to quantify or identify emissions from aircraft and ground support equipment (GSE) as they affect aircraft contrails, emissions from GSE, and improved emissions rate data and modeling.
- EPA/FAA Voluntary Emissions Reduction Stakeholder Process. Convened in 1998, this stakeholder process is formulating a voluntary emission reduction program aimed at reducing the growth in NO_x-related emissions from aircraft and GSE. The process was put on hold for nearly a year following September 11, 2001, but is now focusing on gaining consensus for a GSE-related emission reduction program. Through the EPA/FAA Stakeholder Process, FAA and EPA have collaborated on improved guidance to airports relative to the Clean Air Act General Conformity requirements.
- In late 2003, EPA began a regulatory process for aircraft emissions to bring the U.S. aircraft engine emissions certification standards into alignment with those established by ICAO. The role of the ICAO Committee on Aviation Environmental Protection is to provide guidance and build consensus to set standards associated by individual Member States' efforts underway to understand and reduce aviation emissions, including more stringent gaseous emissions standards, development of methods to assess NOx emissions during climb/cruise, establishment of long term technology goals, and assessment of operational procedures to reduce fuel burn and emissions.

FUTURE VISION

We need to develop the means to understand, quantify, and mitigate aviation emissions of traditional criteria pollutants, as well as newly emerging concerns such as HAPs, diesel emissions, and greenhouse gasses. We also need to conduct the studies needed to scientifically assess health risks, first to human beings and then to other sensitive organisms, from aviation emissions.

RESEARCH NEEDS

The research priorities involving aviation and air quality are summarized by affected types of pollutants below.

Criteria Pollutants, HAPs, and Greenhouse Gasses

- Improve the emissions quantification techniques and tools, including the ability to quantify volatile and nonvolatile PM emissions from aircraft, improve the modeling of pollutant concentrations around airports, and assess the need to evaluate health risks associated with exposure to these emissions.
- Continue study of mitigation techniques to aid in development of emission reductions and evaluate such mitigation measures relative to operational, environmental, and economic consequences.
- Coordinate with international efforts to evaluate aviation's contribution to global greenhouse gas emissions to determine the best course of action for addressing appropriate limitations and reductions being asked of the industry. Assist in the furtherance of scientific understanding of these emission impacts in general, which remains a subject of much dispute.
- Develop methods of effectively communicating to the public the ranges of uncertainty in our analysis capabilities and risks to health associated with these pollutants.

Criteria Pollutants, Noise, and Fuel Consumption

- Conduct research on "clean" aircraft engines and available emissions reductions and understand the interplay among NO_x, CO, VOC, PM, CO_2, noise, and fuel consumption, as well as the interplay among the various emissions.

PM and HAPS

- Fill the key data gaps in the aircraft emissions estimation database for both PM and HAPs.
- Develop a detailed commercial aircraft engine emissions sampling and analysis plan for both particulate matter and HAPs that will provide representative data to more accurately reflect actual aircraft emissions.
- Work with stakeholders such as NASA, FAA, EPA, academia, and industry to collect and analyze PM and HAP data.
- Develop a standardized guideline for airport HAPs assessment (FAA is currently developing guidelines for assessing HAPs at airports and will complete a draft in 2004 for stakeholders' comments).

- Work with other stakeholders to determine the need for characterization of health risks potentially associated with HAP emissions from airport operations (FAA will develop guidance for health risk assessment upon completion of the guidelines for HAPs assessment).
- If deemed necessary, develop a risk assessment–risk management framework that can be used by airports to provide a public health perspective for HAPs from airports and provide meaningful risk information to surrounding communities.

Water Quality

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CRITICAL ISSUES

The effect of airport operations on water quality has been garnering attention as regulators look beyond the more obvious sources of water pollution (i.e., end-of-pipe industrial waste discharged into large water bodies) and attempt to address issues such as storm water runoff and other nonpoint sources. Airports, which typically include large expanses of impervious surfaces and host activities that can generate discharges of potential contaminants (e.g., vehicle and aircraft fueling, maintenance, and deicing), have been subject to the requirements of the Clean Water Act's regulations for over a decade, but the application of these rules to the unique operating environment of airports still is being refined. More recently, other water quality initiatives, such as the identification of impaired water bodies and the efforts to set total maximum daily loads (TMDLs) for specific pollutants for those water bodies, have added complexity to what initially seemed a straight-forward permitting regime.

The relationship—and occasional tension—between protecting the environment and protecting the safety of the traveling public has arisen in the water quality context in two distinct areas:

- Deicing and anti-icing agents, used to ensure safe operations in freezing temperatures or other conditions in which frost may form on aircraft surfaces, may have environmental impacts. Although some questions have been raised about potential releases of air emissions from deicing agents, most attention has been focused on the potential for deicing agents to become entrained in storm water and carried through the storm sewer system into nearby bodies of water. Recent improvements in deicing technology have allowed airlines to minimize the use of deicing agents, but the desire to reduce potential pollutants from entering these waters must be balanced by the need to prevent aviation accidents. In addition, recent studies have looked at the potential toxicity of certain additives to deicing fluids. Management of these constituents by airports may be more difficult, because the precise composition of the additive packages is typically considered proprietary information by the manufacturers.
- For historical reasons, many airports are located on or adjacent to large bodies of water (e.g., LAX, SFO, BOS, DCA, JFK). These water bodies, along with associated marshes and other wetlands, often provide habitat for a large number of birds and waterfowl known to cause severe aircraft damage or aircraft crashes. Some of these avian species are protected federally. Enhancing and preserving the water quality of these habitats is an important goal of the Clean Water Act. At the same time, birds inhabiting these areas present a hazard to aircraft,

especially during approach or departures at altitudes of 2000 feet or less, within which more than 90 percent of aircraft-wildlife strikes occur. The incidence of bird strikes is rising, attributable in part to significant improvements in the quality of these habitats and increasing air traffic.

CURRENT STATE

Research is conducted by airports, government agencies, and industry organizations:

- Airports are conducting airport-specific research. Some airports have committed substantial resources to studying the quality of their discharges, either for purposes of developing site-specific data in the course of permitting proceedings, or for the purpose of making decisions on the deployment of technologies to minimize overall impacts. As more of these data become available, we will be better able to generalize about discharges from airports.
- EPA conducted a study of the potential water quality impacts of airport deicing several years ago in conjunction with its Effluent Limitations Guidelines (ELG) program. At that time, the agency made the decision not to proceed with ELGs for the aviation sector. More recently, EPA issued a new Effluent Limitations Strategy, which once again declined to develop ELGs for airport deicing activities; however, some states have set a variety of numerical limits for individual permits, and the possibility remains that the agency will take this issue up again in the future.
- The Society of Automotive Engineers' Aerospace Division has developed and adopted standards limiting the aquatic toxicity of new formulations of Type I aircraft deicing fluids. The Society remains open to the possibility that those standards may need to be made more stringent and also may be open to the imposition of similar environmental performance standards for other types of aircraft deicers and for pavement deicing products.
- Research conducted to date on the biological effects of deicing agents has been conducted at room temperatures, not representing real-world temperatures present when most airports apply the agents. Since most aquatic communities are cold blooded, temperature affects their respective physiologies and oxygen demands. As a result, room temperature bioassays may not be providing a true picture of how these agents are truly affecting the dissolved oxygen needs of aquatic resources. Bioassays performed at cold water temperatures would provide data for water temperature conditions existing in most cases when the agents are applied and discharged.
- Research on constructed wetlands is being conducted as an alternative means of treating storm water runoff and industrial waste using holding areas stocked with plant communities designed to mimic the functions of wetlands. As adapted to airport environs, these artificial wetlands also must be designed to minimize wildlife hazards. Several prototypes have been constructed or are in the planning stage at airports.
- FAA, EPA, U.S. Fish and Wildlife Service, Department of Agriculture, and Department of Defense have been coordinating to more effectively address aircraft-wildlife strikes under a 2003 interagency Memorandum of Agreement (http://www.faa.gov/arp/environmental/5054a/wildhazmou.pdf). FAA also is working with the U.S. Fish and Wildlife Service on a separate agreement to address migratory bird issues and aviation in response to Executive Order 13186 (66 Federal Register 3853, January 17, 2001).
- Airports are improving monitoring techniques. Advances have been made in technology that allow for continuous and real-time monitoring of airport storm water. A number of airports recently have installed systems that will provide useful data, as well as valuable experience with such technology.

- The American Association of Airport Executives is in the process of gathering information about existing and proposed plans so that trends and best practices for controlling storm water can be more easily identified. Currently, there is no comprehensive source of information about airport storm water plans other than the dated material offered by the EPA in 1990 and what is available from individual state environmental agencies.

FUTURE VISION

We need to encourage the development of programs to address a number of specific aviation needs relating to water quality:

- A database or other system of collecting and analyzing information about airport storm water plans.
- A means of sharing information on pavement deicing studies between the aviation and the highway sectors, specifically to compile lessons learned about water quality impacts and potential corrosive effects of particular deicing agents or practices.
- Education of regulatory agencies and environmental groups about the interrelationship between wildlife management at airports and the hydrological function of wetlands and dissemination of research that seeks to reconcile the two.
- A forum for the discussion and dissemination of research on alternatives to chemical deicing, storm water and waste water management practices at airports, and new technology that could assist in compliance with water quality requirements.

RESEARCH NEEDS

Specific research needs involving aviation and water quality are the needs to

- Assess biological impacts of deicing agents in real-world conditions. Bioassays should be conducted at colder water temperatures replicating conditions existing in most cases when the agents are applied and discharged. In addition, more research needs to be conducted to determine whether additives contribute to water quality problems at airports.
- Develop new deicing agents. The advertised environmental benefits of new deicing agents need to be matched by study of potential adverse effects of new agents on operations and equipment (e.g., corrosivity of potassium formate, corrosion protection offered by triazole-free aircraft deicing agents).
- Find alternatives to chemical deicing agents. Reducing reliance on chemical deicing agents can have significant benefit in terms of water quality. Additional research is needed to develop additional nonchemical deicing methods and to reduce the costs and improve the functionality of those already shown to be feasible technologically.
- Refine storm water management techniques. Continued research into the control and treatment of storm water in an airport environment is needed to improve water quality and reduce compliance costs.
- Develop appropriate discharge obligations for airports. Airports may be subject to regulatory requirements under several different water programs, including the National Pollutant Discharge Elimination System, TMDLs, and water quality certification for infrastructure construction. The aviation sector needs to identify and to participate in the development of these programs at the state and national level, and discharge obligations of airports need to be assessed accurately in order to provide a sound baseline for project designs.

- Further research and develop best practices for reducing the role of wetlands and water bodies in attracting wildlife hazards to airport environs without compromising their hydrological function or reducing habitat for threatened and endangered species. This may include identification of plant species or plant communities that do not attract the kind of wildlife that poses a hazard to aircraft operations, more sophisticated methods of assessing habitat quality, and better mapping of wetlands and other aquatic habitats.

Environmental Process

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CRITICAL ISSUES

Consideration of environmental issues at airports is often a complex and inefficient process, both in terms of environmental documentation for proposed development and in terms of ensuring that airport operation meets applicable regulatory and other requirements. Protracted environmental documentation may impede development and increase costs on the one hand and fail to realize important objectives in terms of resource protection and preservation of quality of life values on the other. Agency enforcement of regulatory standards in a command-and-control mode may fail to provide environmental benefits in proportion to financial costs.

The form and implementation of environmental review and compliance processes are important for determining whether critical stakeholder needs are met. A complex set of laws and policies guides airport development, airspace changes, compliance with environmental requirements, and development of aviation technology and products. Environmental review, rulemaking, and enforcement roles are shared among a number of entities at the federal, state, and local levels (e.g., the Federal Aviation Administration, airport owners, the Environmental Protection Agency, Army Corps of Engineers, U.S. Fish and Wildlife Service, state environmental agencies, and municipalities). These activities often are undertaken in an uncoordinated way that can increase the time, cost, and difficulty of project approval and compliance with environmental requirements but that may or may not advance the goals established for the process. Public opposition and litigation on environmental grounds also add time and increase the uncertainty of the environmental review processes.

Environmental issues associated with aviation are critically important to the future development of aviation infrastructure. Environmental concerns are primary factors constraining the development of additional airport capacity in many areas. Both the perception and the reality of noise, air pollution, traffic congestion, and other environmental effects—as well as the level of trust or confidence in analyses of these effects and the ability to mitigate them—drive political, legal, and other decisions that affect the ability to expand the aviation system. Similarly, decisions regarding aviation have real effects on the environment that may or may not be fully consistent with federal, state, and local environmental assessments preceding the decisions. Accordingly, an improved understanding of the strengths and weaknesses of the environmental review and compliance processes associated with aviation is critical.

CURRENT STATE

In the fall of 2000, the aviation industry and Congress gave increased attention to the benefits of additional capacity at congested airports. Many stakeholders identified environmental processes as causes for delays in implementing capacity initiatives. Government and industry entities increased efforts to evaluate how well current environmental processes work within the aviation context and to identify means of better meeting the goals of environmental requirements. These efforts included the Department of Transportation's Report to Congress in 2001, *Environmental Review of Airport Projects,* and the U.S. General Accounting Office's *Aviation and the*

Environment Airport Operations and Future Growth Present Environmental Challenges (August 2000). Industry organizations such as Airports Council International and the American Association of Airport Executives identified proposals to address perceived shortcomings of current processes. Environmental organizations also have expressed concerns with the manner in which aviation environmental issues are addressed.

FAA has implemented recently streamlining initiatives identified in the Department of Transportation's Report to Congress. In 2002, the President issued Executive Order 12374 to promote environmental stewardship and expedited environmental reviews of high-priority transportation infrastructure projects, including airport infrastructure. Congress recently included provisions intended to streamline environmental review for aviation projects in the FAA reauthorization bill for 2004–2007. In June 2004, FAA issued an updated version of its agencywide guidance on environmental policies and procedures (Order 1050.1E). Despite these initiatives, there is still a considerable gap in knowledge regarding aviation-related environmental review and compliance processes. There has been relatively little study conducted by neutral parties to determine objectively and empirically the effectiveness of these processes and the causes of the sometimes lengthy time periods to review and approve airport projects.

FUTURE VISION

We need to improve the process of addressing environmental issues at airports. This effort will require improved analytic tools, incentives for and new methods to ensure timely interagency cooperation, elimination of procedural requirements that slow and complicate processing without producing clear benefits in terms of decision making, and the use of communications technologies to enhance the intelligibility and transparency of environmental processes to which the public has access.

RESEARCH NEEDS

Research is needed to support improvements in environmental review and compliance processes to better achieve timely development of aviation services and the protection of the environment. Environmental review and compliance processes should inform decision makers and the public of the environmental impacts of projects, support selection and implementation of projects that promote transportation and environmental goals, ensure compliance with environmental requirements, work within reasonable and predictable timeframes, and minimize cost. Objective and empirical research regarding the effectiveness, efficiency, accuracy, and shortcomings of environmental processes applicable to aviation, as well as potential means to improve these processes would be useful to policy makers in evaluating whether existing processes should be changed and in what manner. Many of these research needs arise primarily in the context of the environmental review of new aviation projects, although others relate primarily to ongoing compliance with environmental requirements. Both the environmental review and compliance contexts are important to the protection of the environment and the health of the aviation industry.

Specific research needs involving the aviation environmental process are the needs to

- Determine the amounts of time that environmental review and compliance processes add to airport, airspace, and other aviation projects;

- Identify the probable causes of any added approval time, including multi-agency coordination issues, genuine environmental problems, inability to mitigate, disputes over purpose and need, community opposition, project revision, and lack of resources;
- Locate critical bottlenecks in the environmental process and develop possible solutions that would still meet process goals;
- Assess the effectiveness of environmental documents' communication of impacts, risk, and complex topics (e.g., noise, air pollution, air toxics, capacity, and forecasts) to the public;
- Develop approaches for conveying environmental information in the aviation context in a brief, accessible, and meaningful way;
- Evaluate the forecasts, assumptions, and predictions made in previous environmental reviews in light of actual experience;
- Consider the effectiveness of sustainable practices and programs (including environmental effects, costs and benefits, and relationships with affected communities);
- Review the adequacy of mitigation tools available to address community concerns and opposition, as well as the effects of mitigation on the process;
- List the factors critical to addressing community opposition and concerns;
- Apprise the effectiveness of environmental management tools, as well as alternatives to the command and control compliance model in the aviation context;
- Study the effects and adequacy of legal processes affecting aviation environmental planning, such as land use and metropolitan transportation planning processes, occupational safety litigation, and takings and nuisance litigation; and
- Evaluate the effectiveness of components of the environmental review process and develop measures to benchmark best practices.

Tools

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CRITICAL ISSUES

The adverse environmental by-products of aviation increasingly affect civil aviation's capacity to grow and to operate unrestrained nationally and internationally. Although there are multiple by-products and interdependences that are important to understand, noise and air pollutant emissions are particularly critical and more directly dependent on aircraft and engine design. Delivering technologically and economically feasible decreases in noise and emissions is a growing challenge. Substantial progress already has been made, particularly in reducing jet engine noise. However, passenger and cargo aircraft and gas turbine engines are maturing technologies, and the growing complexity of aircraft systems compels an interdisciplinary approach to aircraft design to achieve future advances. Moreover, progress in noise and emissions mitigation must employ a mix of source reduction technologies with operational procedures, controls, and land use management to reduce exposure to the sources. The challenge is to understand the interdependencies between aircraft noise and aviation emissions and among various emissions to optimize mitigation strategies and to minimize environmental impacts as a whole. Exploiting continuously increasing computing power will play an important role in achieving that understanding.

We must develop superior decision support tools that enable an interdisciplinary approach to assessing aviation environmental impacts and interrelationships. These tools must give decision makers—including the aviation industry, government, and the public—the information needed to develop responsive strategies that allow aviation to grow in an environmentally responsible manner. The aviation industry needs to analyze the noise and emissions interdependencies in both the design and operating contexts. Government agencies need to assess the consequences of proposed environmental actions and policy decisions in terms of the effects on noise and air pollutant exposure. The public needs reliable and clear information on noise and emissions impacts to participate effectively in decision making that could affect health and welfare. Assessing impacts and interrelationships is a complex issue, and it will take time to develop interdisciplinary decision support tools. Meanwhile, it is important to maintain a state-of-the-art analytical capability to support ongoing needs for aviation noise and emissions analyses.

CURRENT STATE

FAA has been at the forefront of developing and deploying models to evaluate aircraft noise and aviation air pollutant emissions around airports, notably the Integrated Noise Model and the Emissions and Dispersion Modeling System. FAA also has developed a Model for Assessing Global Exposure to Noise from Transport Aircraft and more recently developed the System for Assessing Aviation's Global Emissions, which estimates aircraft fuel burn and emissions over the entire international and domestic flight regime. NASA is at the forefront of developing aircraft and engine design and analyses models that also encompass noise and emissions

predictive capabilities. These models include Aircraft Noise Prediction Program, Advanced Vehicle Analysis Tool for Acoustics Research, and NASA Engine Performance Program.

Efforts to address aircraft noise and aviation air pollutant emissions issues have advanced largely along independent paths. There are separate modeling tools, research projects, analyses, metrics, and decisions. This reflects the complexities of each issue as well as the makeup of the broader aerospace community (including manufacturers, academia, and government entities), which historically has treated noise and air pollutant emissions as separate disciplines.

Although there has been some crossover in recent years, such as incorporating aircraft performance data from noise models into emission models, the current level of integration is not sufficient to meet today's and future needs.

FUTURE VISION

We need to base future environmentally responsible aviation policy and rulemaking on a new, interdisciplinary approach. This approach must be made as affordable as it is effective. Existing analytical tools are inadequate to assess interdependencies between noise and emissions or analyze the cost–benefit of proposed actions. Accordingly, FAA plans to develop a robust new comprehensive framework of aviation environmental analytical tools and methodologies to perform these functions. The long-term aim is to provide a seamless, comprehensive set of tools to address all aspects of noise and emissions. The elements of this framework will include the following:

- Environmental Design Space (EDS) to provide integrated analysis of noise and emissions at the aircraft level.
- Aviation Environmental Design Tool (AEDT), comprising EDS and other integrated aviation noise and emissions modules, to provide integrated capability of generating interrelationships between noise and emissions and among emissions at the local and global levels.
- Aviation Environmental Portfolio Management Tool (APMT), comprising AEDT and other modules, to provide the common, transparent cost–benefit methodology needed to optimize national aviation policy in harmony with environmental policy.
- This framework of tools will allow the following:
  - Government agencies to understand how proposed actions and policy decisions impact and are impacted by aviation noise and emissions,
  - Industry to understand how operational decisions impact and are impacted by proposed projects affecting aviation noise and emissions, and
  - The public to understand how actions by government and industry impact and are impacted by aviation noise and emissions.

FAA asked TRB to assist it in defining the attributes and requirements of the new toolset. A three-day workshop was held in March 2004 to gather input from experts to aid in developing the toolset. Nearly 70 specialists from academia, industry, government, and environmental groups attended the workshop. Follow-on activity by the TRB is expected to review, evaluate, and comment on the initial development effort.

RESEARCH NEEDS

An interdisciplinary approach to noise and emissions modeling builds on continued improvement of individual noise and emissions modules. Related tasks include developing and validating databases and methods used to assess aircraft noise exposure and impacts, aviation pollutant emissions and impacts on air quality, and global aviation emissions and impacts on climate. Specific research needs involving aviation environmental tools are

- For AEDT, combine existing NASA acoustics and engine emissions modules into an integrated package for evaluating interrelationships between noise and air pollutant emissions, taking into account aircraft cost considerations, design, and operational factors (e.g., time in mode). We must create the software architecture, design module links, and harmonize database architecture. We must create user interface and output protocols. This effort also includes troubleshooting and optimizing the software design.
- For APMT, integrate the AEDT with suitable traffic and econometrics modules and socioeconomic data. This effort also includes creating a user interface and output protocol, troubleshooting, and optimizing the software design.
- For both the AEDT and the APMT, conduct a quantitative assessment of uncertainty. This assessment will provide guidance on the level of confidence that we can place on tool outputs and encourage international acceptance. The assessment also will provide a research road map for improving the tools with specific, quantitative metrics for measuring this improvement.

FAA plans to pursue development of both the AEDT and APMT and imagines uses ranging from design and technology impact studies to airport improvement projects to noise and emissions certification standards rulemaking. FAA is seeking participation from academia, industry, government, and environmental groups on this initiative.

Technology Deployment

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The deployment of environmental technologies within the aviation industry appears to have slowed over the past decade. Today's slow pace and limited scope of aviation-related environmental technology deployment are due partially to the fact that the aviation private sector and the products that serve it are mature markets. Shifting relationships between the aviation private sector and the combination of government entities that regulate the industry or support preproduction research alter incentives to develop and deploy new technologies. Relations among government entities vary over time, altering the direction and funding of technology emphases and delaying their implementation. Although a full examination of the state of research, a vision for the future, and research needs in this area are beyond the current scope of this paper, several critical technology deployment issues can be identified, as noted below.

- The pace of innovation via all new products has decreased as an expected outcome of the industry maturing. Aircraft types have been developed for each of the feasible ranges of speed and size for commercial aircraft. The economic barrier to replace an existing product in the same size/speed class is high. In addition, increased risk aversion on behalf of all components of the enterprise has been triggered by a need to ensure that new environmental technology meets high reliability, durability, maintainability, and increasingly significant security standards.
- There is a perception that commercial aviation is not a business in which original equipment manufacturers should invest if they are not invested already in the industry or if they have alternative investment options. Other sectors (e.g., home building) take precedence owing to the larger and expanding size of those markets. For example there is minimal fuel cell or micro turbine research concentrating on airport markets.
- There are an increasing number of technology trades (e.g., CO_2 and noise versus NO_x) that force suboptimization of the ability to meet any one technical characteristic without sacrificing others. Selection of a product option that produces overall gains of significance has become more difficult over time. Trade offs between environmental and nonenvironmental characteristics such as capacity further reduce cost effective options.
- Government agencies such as FAA and NASA are reducing their support of technologies up to the system demonstration level. This level in NASA nomenclature is referred to as Technology Readiness Level 6 (TRL6), the generally accepted prerequisite for industrial development and deployment initiation. During the 1980s, NASA sponsored both engine and aircraft full-scale demonstrations under its aircraft energy efficiency program, and when taken to TRL6, produced significant near term innovation in commercial products. This reduction in deployment funding does not appear to be occurring in Europe, where funding either is more concentrated within the industry sector or is supported at multiple government levels (e.g., European Union, nation, and province).

- There are few mechanisms to trigger examination of issues in a manner that balances research and regulatory policy within the scope of a given environmental concern. A counterproductive regulatory process can stunt rather than speed innovation.
- New or emerging issues, particularly those that are not governed by aviation-specific regulatory bodies (e.g., particulates, HAPs, water regulations), need to trigger aviation-specific research. For example, in the case of particulates, formation physics at ultra-high (50 to 60 atmosphere) pressures and measurement approaches need to be established in lieu of extending measurement techniques developed for application to other engine cycles (e.g., diesels) used in transportation.

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. On the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Bruce M. Alberts is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. William A. Wulf is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, on its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both the Academies and the Institute of Medicine. Dr. Bruce M. Alberts and Dr. William A. Wulf are chair and vice chair, respectively, of the National Research Council.

The **Transportation Research Board** is a division of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. The Board's mission is to promote innovation and progress in transportation through research. In an objective and interdisciplinary setting, the Board facilitates the sharing of information on transportation practice and policy by researchers and practitioners; stimulates research and offers research management services that promote technical excellence; provides expert advice on transportation policy and programs; and disseminates research results broadly and encourages their implementation. The Board's varied activities annually engage more than 5,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.
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