TRANSPORTATION RESEARCH
CIRCULAR

Number E-C138 September 2009

Critical Issues in Aviation and the Environment 2009

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

TRANSPORTATION RESEARCH CIRCULAR E-C138

Critical Issues in Aviation and the Environment 2009

TRB Environmental Impacts of Aviation Committee

September 2009

Transportation Research Board
500 Fifth Street, NW
Washington, DC 20001
www.TRB.org

TRANSPORTATION RESEARCH CIRCULAR E-C138
ISSN 0097-8515

Transportation Research Board
500 Fifth Street, NW
Washington, DC 20001
www.TRB.org

Glenda J. Beal, Production Editor; Jennifer Merrill Thompson, Proofreader; Jennifer J. Weeks, Layout

Contents

Introduction

MARY ELLEN EAGAN
Harris Miller Miller & Hanson Inc.

DAVID O. BELL
Aviation and Environment News

These are tumultuous times in the aviation industry, as stakeholders struggle to respond to uncertain fuel prices and availability, a global economic and financial crisis, and increased scrutiny of environmental impacts of aviation. The potential impacts of aviation on climate—and impacts of climate on aviation—are of particular concern and urgency.

Efforts to minimize environmental impacts increasingly dominate aircraft design and the design, construction, and operation of airports. As a result, environmental issues have become a fundamental constraint to increasing aviation system capacity, while constrained capacity only exacerbates environmental problems.

Some environmental impacts are well understood, while others will require significant research to understand existing and future environmental impacts and the opportunities for mitigating or avoiding them. For example, better science-based understanding of the impacts of aviation emissions on climate change is needed to formulate an appropriate response. In addition, improved metrics, measurement techniques, and modeling capability are needed to quantify and predict impacts and to understand interrelationships of aviation environmental issues. This circular summarizes the progress being made and suggests additional research to help achieve that vision.

OVERVIEW

The Transportation Research Board (TRB) Environmental Impacts of Aviation Committee issued its first summary of critical issues in aviation and the environment in the United States in 2004, followed by a second edition in 2005. This revision updates and expands upon the previous circulars while maintaining their cross-disciplinary approach to reviewing subjects of interest to the civil aviation community. It consists of nine individually authored sections representing the authoring experts' opinions on issues that address the major environmental media affected by aviation activities and the key processes that link aviation and the environment, including three sections new to this edition: climate change, alternative fuels, and sustainability. As before, the focus is on the state of science, rather than on policy, and on identifying priority research with the potential to yield benefits during the next several years to several decades. Each section is divided into subsections that

- Define the critical issues in the subject 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.

This circular focuses on research conducted in the United States, although international activities are discussed where public or private entities in this country are closely involved. A wide range of published and unpublished material, public information, and individual contributions was collected to prepare these papers, as noted in the references at the end of each section. Because of constraints on time and effort, the Critical Issues portions of each section do not necessarily address all potentially critical issues in a given field. For example, this circular does not fully address land use development near airports, which represents a major constraint on future aviation activity and for which effective controls remain to be developed. Threatened and endangered species, air and drinking water quality inside aircraft and airports, and other topics also are not addressed but might be added in future revisions. The critical issues listed here have varied and evolved over time and will continue to do so. For example, while aircraft noise impacts once were preeminent 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 individually authored section addresses efforts to advance the resolution of the issues now underway in the broad community of professionals concerned with aviation and the environment. To this end, TRB maintains committees and task forces that focus on specific environmental topics, such as noise and air quality, as well as committees concerned with various aspects of aviation. The Environmental Impacts of Aviation Committee coordinates with these committees in planning meetings, annual meeting sessions, paper reviews, and related matters. The Current State portions of this circular help to further one of the Environmental Impacts of Aviation Committee's goals: 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 Federal Aviation Administration (FAA) reauthorization bill enacted by Congress in December 2003 included extensive environmental provisions designed to streamline environmental review processes and mitigate noise and air quality impacts on airport communities. It also chartered the Joint Planning and Development Office (JPDO), tasked with designing and implementing the Next Generation Air Transportation System (NextGen) to accommodate future demand. The proposed FAA Reauthorization Act of 2009 features a provision that would establish the Continuous Lower Energy, Emissions, and Noise (CLEEN) engine and airframe technology program, charged with developing technology to increase fuel efficiency by 33%, reduce landing and take-off emissions of nitrogen oxide by 60%, and reduce noise levels 32 decibels below the current international standard.

As the JPDO moves forward with NextGen, programs such as CLEEN could be vital to meeting its environmental goals of achieving absolute reductions in significant impacts on community noise levels and local air quality, limiting or reducing the impact of aviation greenhouse gas emissions on the global climate, reducing significant impacts on water quality, improving energy efficiency through the national airspace system, and supporting the development of alternative fuels for aviation. In the meantime, the JPDO's environmental working group is developing a comprehensive environmental policy to address impacts of primary concern and establish specific targets for noise, local air quality, airport water quality, and global climate change, as well as policies to enable technology development and insertion into the fleet in a timely manner sufficient to meet NextGen environmental and capacity enhancement goals.

In 2003, two major programs focused on aviation environmental research were established: the Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER) and the Airport Cooperative Research Program (ACRP). PARTNER is an FAA Center of Excellence cosponsored by the National Aeronautics and Space Administration and Transport Canada, and designed to foster breakthrough technological, operational, policy, and workforce advances in aviation noise and emissions reduction. To date, PARTNER has undertaken more than 25 projects, including a 2004 report to Congress that proposed a national vision statement and recommended actions regarding aviation and environment.

The 2003 FAA reauthorization bill established the ACRP to fund research projects identified by airports as having high priority, clearly defined objectives, and immediate practical applications. To date, the ACRP has funded or approved 15 research projects directly related to environment, including investigations into greenhouse gas emissions, hazardous air pollutants, particulate emissions, community responses to aircraft noise, alternative deicing and anti-icing formulations, alternative fuels, and a comprehensive development plan for a multimodal noise and emissions model. The Research Needs portions of this document draw on recommendations detailed in the National Research Council report that led to the establishment of the ACRP, as well as additional needs subsequently identified by the section authors. Research needs identified in this circular could, in turn, suggest projects that can be realized through PARTNER and the ACRP.

ACKNOWLEDGMENTS

This circular contains nine individually authored sections that represent the viewpoints of the attributed authors. Members and friends of the Environmental Impacts of Aviation Committee also reviewed and contributed comments to these sections. Specific acknowledgment is extended to the following contributors for their helpful assistance during the committee review process:

- Lourdes Maurice, *Federal Aviation Administration, Office of Environment and Energy;* and
- David O. Bell, *Aviation and Environment News.*

The TRB Environmental Impacts of Aviation Committee welcomes comments on this document. Please address them to the Committee Chair.

REFERENCES

Transportation Research Board, 2004. Electronic Circular E-C069: *Critical Issues in Aviation and the Environment*. Posted at http://gulliver.trb.org/publications/circulars/ec069.pdf.

Transportation Research Board, 2005. Electronic Circular E-C089: *Critical Issues in Aviation and the Environment*. Posted at www.trb.org/publications/circulars/ec089.pdf.

Noise

MARY ELLEN EAGAN
Harris Miller Miller & Hanson Inc.

RAQUEL GIRVIN
LOURDES MAURICE
Federal Aviation Administration

Aircraft noise historically has been a major constraint to increasing civil aviation capacity. Despite the facts that community exposure to aircraft noise has decreased markedly over the past several decades and that the United States and the European Union have ambitious technology goals for the future, community 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 and to improve the compatibility of lands near airports with their respective noise exposure. Other research efforts have focused on operating aircraft in ways that reduce noise impacts and on planning airports and surrounding communities to avoid exposing sensitive land uses, such as homes and schools, to aircraft noise. Aviation noise research in the United States is conducted in different institutional settings, including federal and state governments, industry, universities, and private consulting firms.

Federal agencies coordinate research priorities and findings through the Federal Interagency Committee on Aviation Noise (FICAN). Its members include the Department of Transportation, Department of Defense (DoD), Environmental Protection Agency (EPA), the National Aeronautics and Space Administration (NASA), Department of Housing and Urban Development (HUD), and Department of the Interior (DOI). Research also is coordinated through the Joint Planning and Development Office (JPDO) Environmental Working Group, which consists of the Federal Aviation Administration (FAA), NASA, EPA, DoD, Department of Commerce, Council on Environmental Quality, DOI, and Office of the Secretary of Transportation (OST), as well as industry, academia, local government, and community groups. Research undertaken by these agencies includes the following:

- NASA's Aeronautics Research Mission Directorate Fundamental Aeronautics Program is pursuing research and development (R&D) aimed at reducing noise produced by aircraft. NASA's aviation noise efforts focus primarily on what NASA refers to as fundamental research, which is the relatively early phase of R&D that, to be successfully implemented, requires further development by aircraft and engine manufacturers.
- DoD coordinates research across the services through its Unified Airborne Noise Program, which is coordinated through the Defense Noise Working Group. DoD has developed

tools in support of the Air Installation Compatible Use Zone program and National Environmental Policy Act documentation. NOISEMAP is used to model noise exposures in the vicinity of a military air base due to aircraft flights, maintenance, and ground run-up activities. The Rotorcraft Noise Model is used to calculate noise exposure specifically from helicopters and tilt wing aircraft such as the V-22 Osprey. Other models include the Military Operating Area and Range Noise Model (MR_NMAP); ROUTEMAP, for predicting noise levels from aircraft flights on military training routes; and other supplemental tools. Future development plans include migration from energy-based models, such as NOISEMAP and supporting suites of tools, to time-based simulation models, which use noise hemispheres as the source definition for development of noise footprints.

- DoD has been the primary agency funding research on aviation noise effects on animals, including studies on Mexican spotted owls, red-cockaded woodpeckers, marine mammals, and other aquatic animals. Also, 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 has initiated development of a new toolset that integrates engine and aircraft design with aircraft operations to examine environmental performance and technology development and cost–benefit of actions to mitigate environmental impact. TRB assisted FAA in developing the model by facilitating workshops and soliciting input on FAA's plan from the aviation user, operations, manufacturing, and research communities. Based on this input, FAA has launched the necessary research to develop the toolset and has made substantive progress on a broad range of technical work items.
- FAA, Transport Canada, and NASA are sponsoring the Air Transportation Center of Excellence for Aircraft Noise and Aviation Emissions Mitigation, called the Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER). Established in 2003, PARTNER has developed a strategic plan that includes noise, emissions, and interdependencies elements. PARTNER currently has several projects dealing with noise underway, including the following:
  - *Project 1: Low-Frequency Noise (project completed)*—The goal of the low-frequency noise (LFN) project was to assess the impact of and metrics that quantify low-frequency noise in residences near airports. The study has been completed and the final report was published in April 2007. While the report outlines many findings, perhaps the most salient finding is that LFN is very site-specific. The report offers criteria for identifying the potential for LFN and methodologies for conducting assessments.
  - *Project 2: Source Emission and Propagation (previous title: Quantifying and Mitigating the Impact of Aircraft Noise on People)*—The overall objectives for this restructured project are to develop improved models for the emission of sound from aircraft and propagation from source to receiver. In the near term, the project aims to develop an improved model for thrust reverser noise emissions, an enhanced propagation model for low frequency noise, and post-processing functions to incorporate effects of terrain and post-boom noise for sonic boom. The long-term objective is to develop more accurate predictions of emission and propagation of noise from aircraft during all phases of operation (taxi, takeoff, cruise, and landing). This research is expected to go on for several years; however, increased funding could accelerate the effort.
  - *Project 4: Continuous Descent Arrival*—Research has proven, through both simulation and flight demonstration tests, that continuous descent arrivals (CDAs) are highly advantageous over conventional "dive-and-drive" arrival and approach procedures. The focus of continuing research efforts is to further develop CDA for

implementation in low-density through high-density traffic. Recently, researchers have completed a report on CDA Procedure Profile Design Process and Criteria (CDA cookbook). Other recent accomplishments include prototyping CDA procedures at candidate airports with carrier and freight applicants, developing business case and cost allocation for a concept of operations plan, coordinating provisions for CDA usage in airspace redesign projects to demonstrate benefits, and identifying and developing operational requirements for cockpit and controller tools to enable CDA implementation.

– *Project 6: Land Use Management and Airport Controls (project completed)*—The objectives of the study involved an effort to better understand the dynamics of land use management, public concerns, and annoyance related to aircraft noise. This study's report was published in December 2007. A follow-on study was also conducted with three additional airports concentrating on the dynamics of land use, which is in contrast with the previous study that focused heavily on noise concerns. The report of this study was published in September 2008. While these projects have provided useful information, there is a need to do a comprehensive assessment of the knowledge gaps and potential for making meaningful progress on land use research.

– *Project 8: Sonic Boom Mitigation*—The goal of this project is to advance the sonic boom metric definition and continue to assess the applicability of existing noise metrics to sonic boom and determine annoyance of low boom waveforms to inform future decision making regarding supersonic flight over land. Research to date has confirmed that existing sonic boom simulators compare well to the sound of real sonic booms, established lexicons and vocabularies for the description of low-boom sonic booms, determined the relative loudness and annoyance of low-boom sonic booms compared to other man-made and naturally occurring transient sounds, and developed preliminary improved metric(s) for the loudness and annoyance of low-boom sonic booms. Research will continue, but true progress is contingent on having an actual aircraft to evaluate.

– *Project 10: NoiseQuest*—NoiseQuest's goal is to develop and maintain a website that is a resource for both airports and communities. It is designed to improve the public's understanding of aviation noise, provide a forum to discuss aviation noise issues, and foster better relations between airports and their surrounding communities. NoiseQuest will facilitate the outreach programs that currently exist and provide an outreach forum for airports too small to have an established community program. The website, www.noisequest.psu, was released in early March 2009.

– *Project 19: Health Effects of Aircraft Noise*—This project's goal is to develop a deeper understanding of how noise affects people's health in communities around airports and eventually to construct models that can be used to predict health impact. Near-term expected project outcomes include a better understanding of where to focus future PARTNER research in health effects of noise and recommendations on the structure of, and methodology for, a long-term longitudinal epidemiological study on health effects of noise. In the longer term, this project is expected to lead toward quantifying the health impacts of noise, which in turn should enable FAA's Aviation Portfolio Management Tool to do a comprehensive assessment of costs and benefits of aviation environmental impacts.

– *Project 24: Noise Exposure Response: Annoyance*—This project is an outgrowth of Project 2. The goal is to develop a deeper understanding of how noise affects annoyance in communities surrounding airports, including the impact of low-frequency noise. Part of the project is to develop a plan for constructing a new aircraft noise simulator capable of accurately re-creating both sonic boom and subsonic aircraft noise inside multiple homes. The expected outcome is to improve models to predict annoyance in communities that are or may be exposed to transportation noise.

– *Project 25: Noise Exposure Response: Sleep Disturbance*—The goal of this project is to understand the impact of aircraft noise on sleep and to develop a sleep disturbance model that is more comprehensive than existing models. This project builds on the outcomes of Project 2 that investigated sleep awakening and sleep structure models. The expected outcome is to have improved tools for assessing, modeling, and predicting sleep disturbance in communities exposed to aircraft noise.

– *Project 26: Sound Structural Transmission*—The goal of the project is to develop noise numerical models to effectively evaluate the transmission LFN through residential building structures such as windows. The expected outcome is to develop means to predict, to categorize, and to improve acoustic performance of LFN transmission to indoors.

FAA, in cooperation with the National Park Service (NPS), 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 is funding research to provide the scientific bases for quantifying and modeling significant noise impact from aviation-related projects in naturally quiet areas. Research program development is coordinated with NPS, and both agencies are seeking opportunities for collaborative research.

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 Chapter 4 noise standard adopted by ICAO, equivalent to the U.S. Stage 4 standard, requires new aircraft designs to have at least a 10-decibel cumulative (i.e., from all three certification points) margin relative to the Chapter 3 standard. The Chapter–Stage 4 standard, which took effect on January 1, 2006, also includes provisions for recertifying existing aircraft to meet the more stringent standard.

DOI 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, with NPS as its lead agency. As part of its efforts, NPS 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 NPS planning process to ensure the preservation or restoration of natural soundscapes. Currently, there is no noise research program at EPA or HUD.

TRB's Airport Cooperative Research Program was authorized by Congress in December 2003 as part of the Vision 100-Century of Aviation Reauthorization Act. In October 2005, FAA executed a contract with the National Academies, acting through TRB, to serve as manager of the ACRP. Program oversight and governance are provided by representatives of airport operating agencies. To date, two research projects and two synthesis projects on noise have been initiated, as described below:

- *Guidebook on Community Responses to Aircraft Noise* (ACRP 02-05)—The objectives of this project are to (1) develop an informative guidebook about local aircraft noise to inform readers with a direct interest, involvement, or investment in airports; (2) develop a toolkit that airport decision makers can use to manage expectations related to aircraft noise within the community; (3) investigate alternative metrics to communicate noise issues to the community; and (4) suggest other improvements that go beyond current practice to ease aircraft-noise issues. For this project, the term "noise issues" involves the socioeconomic, political, operational, safety, environmental, and legal impacts of aircraft noise on an airport; the complaints about aircraft noise from neighbors; the effects that noise has on neighbors; and the communication between the airport and its neighbors. This research should identify the actual jurisdictional authority over various aspects of the aircraft-noise issue, and the obstacles to airport operations and development because of community perceptions of local aircraft noise.
- *A Comprehensive Development Plan for a Multimodal Noise and Emissions Model* (ACRP 02-09)—The objective of this research is to produce a comprehensive model development plan (MDP) that will guide future development (by others) of a model to facilitate integrated quantification of multimodal noise and emissions, as well as economic analysis of alternative scenarios. The model that will result from implementing the MDP will consist of an analytical tool or set of tools in the form of (1) a super model (i.e., a single, inclusive model designed to address all desired components); (2) a tool that combines inputs and outputs of existing or new models; or (3) an alternative approach. Modes to consider should include aviation, rail, transit, maritime, and roadways. This research will define the process required to create this model, but will not result in the actual development of the model. The tasks included in this research will determine the feasibility of an integrated approach to quantification of multimodal noise and emissions, the form that this model might take, and the process required to create the model. Actual development of the model will be considered in the future, as determined by the outcome of this research.

Another ACRP noise-related project currently underway addresses the encroachment around airports of incompatible land use, such as noise-sensitive developments. The objective of *Enhancing Land Use Compatibility* (ACRP 03-03) is to develop guidance to protect airports from incompatible land uses that either impair the efficiency and safety of airport and aircraft operations or constrain airport capacity expansion. This project is scheduled to be completed in 2009. A synthesis study on the effects of aircraft noise, designed to be an update of and complement to the U.S. Federal Highway Administration's 1985 Aviation Noise Effects reports has been published and can be found at www.trb.org/news/blurb_detail.asp?id=9528. Another synthesis study to research airport noise programs in areas outside DNL 65 (ACRP Synthesis 11-03/Topic S02-03) was conducted and the final report will be released soon. The study surveyed airports to identify reasons for addressing noise beyond DNL 65 and what techniques airports use besides sound insulation to address noise issues. Also under development is a quick response study on enhancing taxiway noise prediction capability (ACRP A11-02, Task 8). This is a scoping project that aims at outlining the system and functional requirements in developing the new modeling capability through steps such as analyzing various data, collecting new data if necessary, and conducting sensitivity analysis.

The Next Generation Air Transportation System (NextGen) is a multi-agency (OST, FAA, NASA, DoD, Department of Commerce, Department of Homeland Security, and the Office of Science and Technology Policy), integrated effort to ensure that the future air transportation system meets air transportation security, mobility, and capacity needs while reducing environmental impacts. As noted above, the NextGen JPDO includes an environmental working group that is addressing strategies to reduce aviation's noise impact in absolute terms. The NextGen integrated work plan includes the following operational improvement goal with respect to noise: "Significant aircraft noise is contained within the airport boundary and adjacent areas of compatible land uses through improvements in aircraft engine and airframe technologies, aircraft capability, operational procedures, ensuring compatible land uses, and applying environmental management systems that reduce noise." NextGen has established a target of 2009 for all aviation organizations to adopt an environmental management system for achieving NextGen environmental goals.

To better coordinate research on aircraft noise impacts, FAA is seeking to develop comprehensive research roadmaps in collaboration with and participation of researchers across numerous disciplines and around the world, as well as with the broad community of aviation stakeholders including the public.

FUTURE VISION

Advanced technologies and operational procedures are needed that will further reduce aircraft noise and noise exposure. Because this effort will require time to develop and deploy, there is a need to better understand the relationship between aviation noise and community reaction, and to find ways to make aviation more compatible with nearby communities. Given the uncertainty of the future, it is important to envision a variety of future airspace system scenarios, as well as the ability to more quickly and accurately model the noise from these scenarios. Evaluation of potential noise reduction or mitigation solutions is then needed within the larger context of all the environmental consequences of aviation, including air quality and climate change.

RESEARCH NEEDS

Noise research needs remain in 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, such as navigational-aided departures and approaches and 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 and quality of life. There are 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 and dose-response relationships 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

from urban and suburban to rural and wilderness settings, given the differences in ambient noise levels; other human impacts such as the effects of aircraft noise on children's ability to learn; and the trade-off between actions to reduce aircraft noise and the implications for pollutant emissions and particulate matter.

- Expand research on mitigation and land use compatibility planning. Additional research is needed on the effects of low-frequency noise and vibration, the 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.
- Develop understanding of acceptable noise levels and noise impacts of unconventional aircraft. Given industry's interest in fielding a small supersonic business jet, research is needed to establish sonic boom acceptability, including flight demonstrations to obtain data on community response to sonic booms. Similarly, research is needed on acceptability and impacts of noise from low-fuel burn subsonic aircraft designs with open rotor engines.
- Identify effective strategies to reach out to stakeholders in addressing noise concerns. 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, education programs, and inclusive and participatory planning efforts. Further research is needed to help identify and disseminate these best practices.
- Continue to study effects of aircraft noise on public lands. Research needs include refinement of existing noise models to adequately consider the unique technical issues posed by natural areas, definition of metrics and criteria for evaluating impacts in these areas, and examining the role of noise monitoring in defining and assessing park soundscapes.
- 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—woodpecker weightings and owl weightings, for example. Further work in this area is needed. Another area of needed research is on the cumulative effects on animals to address the combined impact of aviation and other noise sources, such as auto traffic, industrial, pollution, and human interactions.

REFERENCES

Federal Interagency Committee on Aviation Noise: www.fican.org.

Federal Aviation Administration Office of Aviation Policy, Planning, and Environment: www.faa.gov/about/office_org/headquarters_offices/aep.

Center of Excellence for Aircraft Noise and Aviation Emissions Mitigation—Partnership for Air Transportation Noise and Emissions Research: http://partner.aero.

Next Generation Air Transportation System, Joint Planning and Development Office: www.jpdo.aero/site_content/index.html.

Airport Cooperative Research Program: www.trb.org/ACRP.

Air Quality

MOHAN GUPTA
Federal Aviation Administration

BRIAN KIM
ESA Associates

JOHN PEHRSON
Camp, Dresser and McKee, Inc.

MARY L.VIGILANTE
Synergy Consultants, Inc.

Over the past two decades air pollution associated with aviation and airport-related sources has become 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_{10} and $PM_{2.5}$)—from airports account for less than 0.5% of total emissions in the United States, according to the 2003 Government Accountability Office *Report to Congress*. Nevertheless, aviation sources, such as those associated with other transport modes, can contribute to local air quality issues and that contribution may grow. Worldwide aviation traffic is expected to increase at an annual rate of 4.6% over the next decade, albeit this is likely to be tempered by the recent market volatility and oil prices. Increase in aviation demand and activities will likely lead to increase in aviation emissions.

At present, many of the busiest airports in the United States are located in the non-attainment and maintenance areas for National Ambient Air Quality Standards established by the Environmental Protection Agency (EPA). The number of these airports in non-attainment areas is expected to increase as the air quality standards become more stringent. For example, EPA recently revised the 8-hour ozone standard from an effective value of 84 ppb down to 75 ppb. This change has increased the number of counties in ozone non-attainment from 85 to more than 300. In addition, EPA recently lowered the 24-hour PM2.5 standard from 65 micrograms per cubic meter ($\mu g/m^3$) to 35 $\mu g/m^3$.

Numerous sources (aircraft, stationary sources, ground support equipment, ground access vehicles, and auxiliary power units) contribute to overall emissions originating from airport activities. In general, aircraft are the major contributor to airport emissions. Aircraft emit emissions both at the surface and along the flight path. Aircraft emit the bulk of the emissions (~90 percent) above 3,000 ft of altitude. Traditionally, aircraft emissions within the landing-and-takeoff (LTO) cycle and between surface and 3,000 ft have been used for surface air quality analysis. Aircraft emissions within the LTO cycle are controlled by the emission standards established by the International Civil Aviation Organization (ICAO). A recent scientific study suggested that non-LTO aircraft emissions also contribute significantly to the surface air quality

(Tarrason et al., 2004). However, more studies are needed to develop a reliable understanding and estimates of impacts of cruise aircraft emissions on surface air quality.

Aviation emissions, like those associated with other sources, affect ambient air quality. There are no known unique emissions or health impacts associated with aviation emissions. Once emitted, aviation emissions evolve and transform in a similar way as those from other sources and are indistinguishable from those present in the background air. Air quality impacts of air pollutants, including hazardous air pollutants (HAPs) released from any source, encompass a host of issues ranging from the characterization and magnitude of direct emissions to ultimate fate via atmospheric transport and transformation leading to pollutant destruction and formation of secondary air pollutants. Continued advancement is critical toward robust understanding of these issues for proper characterization of the magnitude and extent of changes in air quality and health impacts associated with aviation emissions.

The research needs associated with greenhouse gas and climate change, alternative aviation fuels, and modeling tools are addressed in other sections of this Transportation Research Circular.

CURRENT STATE

As described in this circular's section on Noise (see Page 4), the United States launched a 25-year plan for the Next Generation Air Transportation System (NextGen), under the auspices of the multi-agency Joint Planning and Development Office (JPDO), which includes the Department of Transportation, Federal Aviation Administration (FAA), National Aeronautics and Space Administration (NASA), Department of Defense (DoD), Department of Commerce, Department of Homeland Security, and White House Office of Science and Technology Policy. NextGen involves an integrated effort to ensure the future air transportation system meets air transportation security, mobility, and capacity needs while reducing environmental impacts. The JPDO structure includes an Environmental Working Group that is addressing strategies to reduce aviation's impacts on air quality absolute terms as it identifies research and development needs that will enable advanced modeling capabilities for predicting such impacts, as well as inter-relationships with noise and climate impacts. Specific research and development activity needs and schedules are summarized in the *NextGen Integrated Work Plan: A Functional Outline* (www.jpdo.gov/iwp.asp).

Research activities on aviation emissions and their air quality and health impacts are being pursued in various institutional settings, including federal and state governments, universities, and private consulting firms. Most of the federally funded aviation-related emissions and air quality research as well as health impacts research are carried out by the FAA-NASA-Transport Canada sponsored center of excellence for Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER) and the Airport Cooperative Research Program (ACRP), which is managed by the Transportation Research Board of the National Academies.

- FAA, in coordination with other federal agencies, industry, academia, state organizations, and public interest groups, has developed the Aviation Emissions Characterization (AEC) Roadmap. Formerly known as the Particulate Matter (PM) Roadmap, coordination activities under the AEC Roadmap have been extended to include research activities on all aviation emissions and their environmental impacts. An annual meeting is convened to discuss the AEC Roadmap and a report of the meetings findings is published on the status of national and international research activities and major accomplishments. During the meeting, discussions take place to identify major gaps and uncertainties and also to prioritize the future research agenda. Related to the Roadmap was the development of the First Order Approximation (FOA) to estimate PM emissions from aircraft engines. Currently, Version 3.0 of the FOA is incorporated into the FAA Emissions and Dispersion Modeling System (EDMS) Version 5.1 (www.faa.gov/about/office_org/headquarters_offices/aep/research/science_integrated_modeling/media/(AEC)Roadmap_20081205.pdf).

- Understanding and quantification of aviation emissions is the utmost priority before using this information for characterization of the impacts of these emissions on the ambient air quality. FAA and NASA along with several other agencies (e.g. DoD, Environmental Protection Agency) have funded and participated in a number of campaigns such as the Experiment to Characterize Aircraft Volatile Aerosol and Trace-species Emissions (EXCAVATE), three separate Aircraft Particle Emissions Experiments (APEX), and the Hartsfield-Atlanta-Delta Study on characterization of emissions from aircraft equipped with a modern fleet of engines. The Hartsfield-Atlanta-Delta Study was prepared under the PARTNER program. The ACRP has also completed a study on summarizing and interpreting aircraft gaseous and particulate emissions data from the APEX and Hartsfield-Atlanta-Delta studies (http://onlinepubs.trb.org/onlinepubs/acrp/acrp_rpt_009.pdf).
- Previously, speciation profiles of aircraft hydrocarbon (HC) emissions were based on a single aircraft measurement reported by Spicer et al. (1994). Recently, FAA and EPA joined efforts to revisit the hydrocarbon emissions data representative of various aircraft and engine combinations collected during the APEX campaigns. This effort led to creation of a hydrocarbon speciation profile for jet engine equipped commercial aircraft. This speciated HC emission profile also led to updates of known gaseous emissions of HAPs. This new profile now has only 17 known HAPs, and emission indices of key HAPs are generally lower than those included in the earlier profile included in the EPA SPECIATE database. This newly developed dataset on speciated HC emissions has been included in the latest version of the EDMS model (v 5.1) and is being used in air quality modeling and analysis projected funded by PARTNER and ACRP. Note that this speciated HC emission profile accounts for only 72% of the mass of total HC emissions. Nevertheless, this has been an important development in the characterization of aircraft emissions. A report on this work will soon be jointly released by FAA and EPA.
- Since the release of the last update of *Critical Issues in Aviation Air Quality* in 2005, progress has been made on multiple fronts. Recently ACRP has published two key reports on the review of state of knowledge and research needs associated with aviation-related hazardous air pollutants (http://onlinepubs.trb.org/onlinepubs/acrp/acrp_rpt_007.pdf) and particulate emissions at airports (http://onlinepubs.trb.org/onlinepubs/acrp/acrp_rpt_006.pdf). Ongoing projects including *Measurement of Gaseous HAP Emissions from Idling Aircraft as a Function of Engine and Ambient Conditions* (ACRP 02-03A) and *Guidance for Quantifying the Contribution of Airport Emissions to Local Air Quality* (ACRP 02-08) are addressing aircraft idling emissions and development of guidance material to combine modeling with field measurements to comprehensively assess airport air quality concentrations including chemically reactive pollutants.
- FAA and EPA have jointly carried out the congressionally mandated study under the Energy Policy Act of 2005 (EPAct) on nationwide air quality impacts of aircraft emissions. Following a well-matured risk assessment methodology, also recommended by the International Civil Aviation Organizations (ICAO) Committee on Aviation Environmental Protection (CAEP)

workshop on the impacts of aviation emissions, this study provided the first estimates of nationwide health risk exposure from aircraft. The final report on this study is still under review. Initial results from this study, which have been presented at various conferences and symposiums, indicate that most of the "incremental" health impacts are due to particulate matter as a result of direct emissions of non-volatile PM and secondary formation of volatile PM. PARTNER projects carried out the airport-specific aircraft emissions and health impacts study and concluded the results are consistent with the EPAct study. In fact, these projects also concluded that overall health impacts due to aircraft-related HAPs and ozone changes are relatively insignificant as compared to those due to total PM. These studies also concluded health risk exposure to aircraft-related PM, which for any air pollutant is a product of change in ambient concentration, toxicity, and population distribution, could extend as far as 300 km from the source regions and is consistently dominated by the volatile PM.

- With an eye to reducing emissions as well as noise and fuel burn, PARTNER sponsored a demonstration of the feasibility of using the Continuous Descent Approach (CDA) for multiple aircraft arrivals at Louisville International Airport. The results were positive in that reductions of emission, noise, and fuel burn were achieved, leading to several commercial airports developing specific CDA approaches.
- The aviation community, including government agencies (FAA, EPA, and NASA), industry (manufacturers, airports, and airlines), academia, and professional organizations, is planning to continue and possibly augment efforts to develop better ways of measuring particulate matter and HAPs. For example, the Society of Automotive Engineers (SAE) committee on Aircraft Exhaust Emissions Measurement (E-31) is developing methods for measuring PM emissions from jet engines. In addition, the SAE committee on Aircraft Noise Measure and Noise Aviation Emission Modeling (A-21) is currently developing a guidance document to clarify the different aircraft gaseous and PM emissions modeling methods.
- In support of the Aeronautics Research Mission Directorate, NASA Research Announcements solicit research proposals for projects under the (1) Fundamental Aeronautics Program, (2) Aviation Safety Program, (3) Airspace Systems Program, and (4) Aeronautics Test Program. Under these programs, several aircraft emissions and air quality-related projects are currently ongoing. Examples include emissions assessment of future aircraft technologies under the Fundamental Aeronautics Program and the assessment of local and system-level emissions under the Airspace Systems Program to determine the impacts of introducing new aircraft into NextGen for different future years.

Several state and local regulatory agencies have conducted ambient air quality studies at airports across the country. These studies lay the groundwork for future ambient studies that could potentially focus on apportioning the airports' contributions to local air quality.

- The Rhode Island Department of Environmental Management with support from the Rhode Island Department of Health conducted monitoring studies at T.F. Green Airport located in Warwick, and serving the Providence region. Various organic compounds and carbonyls, as well as black carbon and $PM_{2.5}$, were measured at four locations around the airport and at a fifth location some distance from the airport. The findings indicated that correlation of most pollutants with airport operations or activity could not be made. However, elevated levels of black carbon were correlated with wind directions, indicating the airport could be a substantial source of black carbon.

- The New Jersey Department of Environmental Protection contracted with Environ to conduct monitoring studies around the Teterboro airport. Monitoring locations were established at each end of two runways (four stations), and an Open Path Differential Optical Absorption Spectroscopy system was placed near the north end of the primary runway. Measurements of most pollutants were not conclusive with regard to correlation with airport activity. However, measurement of ultrafine particles (UFPs) did show correlation with aircraft movement along the nearby taxiway and runway.
- The South Coast Air Quality Management District conducted measurements of black carbon and lead (Pb) at Santa Monica and Van Nuys general aviation airports. Results indicated that elevated lead concentrations at the runway ends were substantially higher than the monitors located further from these airports. Because lead is still used in aviation gasoline, the source appears to be avgas-fueled piston aircraft.
- The California Air Resources Board funded a study conducted by the University of California, Los Angeles at Los Angeles International Airport (LAX) to measure $PM_{2.5}$, PAHs, black carbon, and UFPs at the blast fence and in the community downwind of the southern departure runway at LAX. The study findings indicated that peak $PM_{2.5}$ and PAHs were not well correlated with aircraft activity. However, black carbon and UFPs were correlated with aircraft activity when measured at the blast fence, and the size distribution of UFPs measured in the community fell between those measured at the blast fence and those measured at an upwind location not substantially affected by airport activity.

FUTURE VISION

Means to understand, quantify, and mitigate aviation emissions of traditional criteria pollutants need to be developed, as well as pollutants of more recent concern, such as PM and HAPs, diesel emissions, and greenhouse gases. There is also a need to conduct the studies required to scientifically assess health risks—first to human beings, and then to other sensitive organisms—from aviation emissions. Improved tools are needed to aid in communicating the conclusions of such studies to the general public.

RESEARCH NEEDS

Criteria Pollutants and HAPs

- Improve the emissions quantification techniques and tools; improve the modeling of pollutant concentrations around airports; and assess the need to evaluate health risks associated with exposure to these emissions.
- Research the emission reduction benefits of alternative fuels and additives for aircraft and alternative fuel use by ground support equipment and vehicles.
- Determine the most important airport sources contributing to on-airport and off-airport exposure.
- Continue the study of mitigation techniques to aid in the development of emission reductions, and evaluate such mitigation measures relative to operational, environmental, and economic consequences.
- Assist in the advancement of scientific understanding of these emission impacts in general.

- Develop methods of effectively communicating to the public the ranges of uncertainty in our analysis capabilities and risks to health associated with these pollutants.
- Determine the effects of ambient conditions on HAPs emissions.
- Better understand the actual thrust levels used by aircraft during idle and taxi conditions, and determine the corresponding actual HAPs emission rates.
- Quantify HAPs emissions from general aviation aircraft.
- Develop a more reliable understanding of the impacts of cruise aircraft emissions on surface air quality.

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.
- Conduct research to optimize reductions in noise, emissions, and fuel burn associated with operations near airports.

PM and HAPs

- Fill in the key data gaps in the aircraft emissions estimation database for both PM and HAPs. Develop and maintain publicly available databases from peer-reviewed emissions data collected from the exhaust plume of a small sample population of aircraft engines running at idle and increasing to maximum rated power. The aim for testing these various engine types and sizes within the sample population is to develop a data set that represents the national fleet.
- Continue to collaborate with SAE E-31 and other stakeholders, including ICAO CAEP, to develop a detailed aircraft engine emissions measurement protocol for particulate matter that will provide consistent and validated methodologies to acquire accurate aircraft engine emissions data.
- Continue working with stakeholders such as NASA, FAA, EPA, academia, and industry to collect and analyze PM and HAPs data. To date, FAA has worked with the aviation community to collect emissions data from a growing sample of specific aircraft and engines at several airports in the United States. Currently, FAA and others have accumulated enough data and information to begin a review of critical needs, such as information gaps, and how these needs can be addressed from the available information.
- Develop PM emission characterization studies for other airport-related sources such as Ground Service Equipment, Auxiliary Power Units, and aircraft tires and brakes.
- Develop studies to fill in knowledge gaps between PM emissions from aircraft engines and other airport sources, and the evolution of PM size, chemistry, and characteristics in downwind communities.
- Begin summarizing available emissions data regarding specific airport sources that could be used to determine an airport's contribution to local and regional air quality.
- Collaborate with FAA, EPA, and other stakeholders to create and implement a standardized guideline for assessing HAPs from aircraft engines and other airport emission sources. Move from strictly looking at what is currently known about aviation-related HAPs to developing a standardized guideline that takes into account various HAPs assessment methodologies used by airports to assess environmental impacts of planned construction, new

data collected from aircraft parked off-runway with engines running at predetermined thrust settings, data collected at locations where aircraft begin take-off operations on the runway, ambient airport monitoring data, research work produced by PARTNER, and a review of the latest published information on aircraft HAPs to produce a comprehensive, fleet-representative data set.

- Work with other stakeholders to determine the need for characterization of health risks potentially associated with aviation-related HAP emissions. FAA will consider the development of guidance to conduct a health risk assessment upon completion and implementation of the guidelines for conducting HAPs emissions inventories. PARTNER research is underway to identify uncertainties and scientific priorities associated with risk assessments of HAP emissions related to aviation sources, particularly aircraft engines. If research outcomes are deemed to support the necessity for further effort, a risk assessment–risk management framework could be developed for use by airports to provide a public health perspective for HAPs from aviation sources and provide meaningful risk information to surrounding communities.

REFERENCES

California Air Resources Board, 2007. *Final Report: The Development of Exhaust Speciation Profiles for Commercial Jet Engines*. October 31. Posted at www.arb.ca.gov/research/apr/past/04-344.pdf.

EPA Website—www.epa.gov/oar/oaqps/greenbk/o8index.html.

FAA 2003. *Select Resource Materials and Annotated Bibliography on the Topic of Hazardous Air Pollutants (HAPs) Associated with Aircraft, Airports, and Aviation,* www.faa.gov/regulations_policies/policy_guidance/envir_policy/media/HAPs_rpt.pdf.

Joint Planning and Development Office, 2008. *Next Generation Air Transportation System Integrated Work Plan: A Functional Outline*. September 30. Posted at www.jpdo.gov/iwp.asp.

PARTNER Website—http://web.mit.edu/aeroastro/partner/projects/index.html.

Transportation Research Board, 2003. Special Report 272—Airport Research Needs: Cooperative Solutions. Posted at http://trb.org/news/blurb_detail.asp?id=1266.

Transportation Research Board, 2008. Airport Cooperative Research Program (ACRP) Report No. 6. *Research Needs Associated with Particulate Emissions at Airports*. Posted at www.trb.org/news/blurb_detail.asp?id=9252.

Transportation Research Board, 2008. Airport Cooperative Research Program (ACRP) Report No. 7 *Aircraft and Airport-Related Hazardous Air Pollutants: Research Needs and Analysis*. Posted at www.trb.org/news/blurb_detail.asp?id=9374.

Airports, Nonaircraft Emissions, and Climate Change

THOMAS P. KLIN
CH2M HILL

JOHN E. PUTNAM
Kaplan Kirsch & Rockwell LLP

BURR STEWART
Port of Seattle

MARY L. VIGILANTE
Synergy Consultants, Inc.

Policy makers at the international, national, regional, and local levels are paying increasing attention to the effects of anthropogenic (human-made) activities on the earth's climate. Human activities have increased atmospheric concentrations of greenhouse gases (GHGs), which are thought by most atmospheric scientists to increase global temperatures and have other effects on regional and local climate. Aviation operations are among the many anthropogenic activities that result in GHG emissions, such as carbon dioxide (CO_2), primarily from combustion of carbonaceous fuels in aircraft engines. For example, the United Nations Intergovernmental Panel on Climate Change (IPCC) estimated that fuel combustion for aviation contributes approximately 2% to the total anthropogenic CO_2 emissions inventory, and, if left unmitigated, this could grow to as much as 4% by 2050.

This section outlines the current state of knowledge and the types of research needed to better understand the climate change issues that are specific to airports, including evaluation of the potential effects of climate change on airport planning and maintenance. Aircraft generate the substantial majority of air travel-related GHG emissions. For example, the 2006 Seattle-Tacoma International Airport greenhouse gas inventory found that more than 90% of total CO_2 emissions associated with that airport were from aircraft operating above 3,000 ft.

While increased attention is being paid to improving knowledge regarding the effects of aircraft operations on global climate, there also are critical research needs at the airport level. Increasingly, airports are being called upon by state and local governments to provide inventories of GHG emissions and to reduce emissions from sources under their control. Non-aircraft sources of GHGs at airports generally include combustion of petroleum-based fuels in ground access vehicles and facility electrical power generation, consumption of cement in new construction, waste incineration, fire training, and other maintenance and operations activities.

Little research has been conducted concerning the effects of climate change on the air travel industry, specifically the airports that support this industry, or how airports are adapting or can adapt to these changes. The U.S. air transport system is stressed by the growth in demand for air travel over the past decade and the inability of the system to respond with expansion at capacity-constrained airports and modernization of the air traffic system. This stress is particularly evident during poor weather conditions, when the arrival acceptance rates at many airports are radically reduced, often resulting in system-wide delays.

While predicting climate changes on a local or regional level is not precise, most analyses indicate that the frequency and severity of poor weather will increase in many areas. As the climate changes, changes in precipitation—in some areas, an increase in rainfall, and in others, drought—also are to be expected, according to the U.S. Department of Transportation and U.S. Global Climate Research Program. This will further burden already stressed airport and airspace capacity, and might increase aggregate delays. Such changes also will affect the performance of stormwater management and other airport systems. In many locations, it is anticipated that the freeze-thaw cycle could dramatically increase, negatively affecting pavement integrity. These types of conditions could have dramatic effects on the operational efficiency of the air transportation system and could influence airport facility requirements, such as storm water detention capacity and pavement inspection and maintenance programs. Most of the airport facilities, infrastructure, and operations being planned today use 10-year and 15-year planning horizons. To prepare adequately for future needs, it might be prudent for the airport community to quickly size up and plan for the most probable near-term effects of climate change now.

CURRENT STATE

Little work has been done to articulate and identify problems that could arise from climate change and the associated effects on airport facilities and operations.

Regional and Local Assessment of Greenhouse Gases and Their Effect on Climate Change

Under international treaties, GHGs currently are addressed at a national level. However, states, cities, and counties across the United States have begun to take action, responding to local political pressure, state legal requirements, and the perceived lack of action at the federal level.

A variety of state and local programs are being implemented to quantify GHG emissions inventories and establish goals for emission reductions. Many of the inventory approaches use methods that differ from IPCC protocols. No consistent models or estimation protocols exist to predict GHG emissions related to air travel. As a result, state and local aviation GHG emission inventories vary widely in format and results, primarily due to the varying methods and assumptions used to quantify emissions.

Research concerning aircraft-related GHG emissions, their quantities, and their potential contributions to global climate change is ongoing. With aircraft as a notable exception, airport emission sources are similar in nature and emissions to other ground-based mobile sources. However, modeling of nonaircraft GHG emissions in the airport setting has lagged behind modeling for other regional sources. In the past decade, the Federal Aviation Administration (FAA) has assumed responsibility for accurate modeling of airport-related air pollutant sources, with the development and enhancement of the Emissions Dispersion Modeling System (EDMS) and the Aviation Environmental Design Tool. However, the most current version of EDMS (5.02) does not estimate GHG emissions.

A project funded by the Airport Cooperative Research Program (ACRP) in 2007, *Guidebook on Preparing Airport Greenhouse Gas Emissions Inventories* (ACRP Report 6), is designed to provide guidance for developing consistent airport GHG emissions inventories. Some of the questions the guidebook is expected to address are which pollutants to model, what emission rates and metrics to use, how to geographically allocate emissions, and how to avoid double-counting.

The public has access to numerous carbon calculators on the Internet that claim to assess GHG emissions associated with an individual flight. These calculators generally focus only on aircraft-related emissions and do not reflect other emissions related to the air travel experience, such as those from ground travel to the airport and the ground vehicles that service the aircraft. Many of these calculators include a radiative forcing index to compensate for non-CO_2 effects of aircraft travel in the upper atmosphere. These methods are not consistent with each other, nor are they consistent with other subnational, national, or international assessments of aviation-related GHG emissions.

State of Current Research on the Effects of Climate Change on Airports

Climate change might also affect the ability of airports and U.S. airspace to handle expected increases in demand, as well as the means by which they do so. However, the effects of climate change on airports have not been studied in any detail to date, thus no metrics or modeling standards exist. This information will be important as efforts are undertaken by FAA, airports, and other stakeholders to provide additional airport and airspace capacity, including the Next Generation Air Transportation System (NextGen).

NextGen has been cited as critically important, because the current system will not be able to handle air traffic that is expected to increase to one billion passengers by 2015 and double current levels by 2025. In 2007 FAA identified 27 airports that will need additional capacity beyond that available today.

No research has been identified that systematically considers the effects of climate change on the air transportation system infrastructure or operational efficiency, beyond relatively simple assessments of impacts associated with potential flooding of infrastructure at or just above sea level. Substantial disagreement exists concerning exactly how global, regional, and local climate regimes will evolve with increasing atmospheric levels of GHGs. On a global level, these differences primarily relate to the degree to which mean global temperature will change. On a regional or local level, climate change may lead to increases or decreases in precipitation, more severe weather events, and varied changes in temperature. Under some scenarios, it is expected that sea levels would rise and inundate the infrastructure of many coastal cities. Such a permanent condition could resemble the effects that were experienced with Hurricane Katrina in 2005 along the Gulf Coast (likely on a slower basis, but on a much larger scale). The aftermath of Katrina redistributed the population of New Orleans and other Gulf Coast areas across the southern United States, with Houston, Mobile, and Baton Rouge each reporting large in-migrations. Likewise, a significant increase in sea levels could have significant effects in redistributing populations throughout the country, affecting aviation demand and supply patterns nationwide. Natural disasters such as Hurricane Katrina also can place substantial burdens on local airports to serve in disaster relief, human services, and population redistribution.

On lesser extremes, during certain times of the year, increases in the frequency and severity of poor weather are frequent consequences of climate change that are noted in research. No assessment is known to exist regarding changes in the frequency of instrument meteorological conditions, which can halve the arrival acceptance rate at many airports.

Storm water and adverse local air quality impacts also are anticipated. Research indicates that there is likely to be an increase in average annual rainfall or the size of peak rainfall events at many locations, potentially affecting the sizing and design of storm water detention facilities. Many researchers have noted the likelihood of further degradation in local air quality as climate changes occur. For instance, as temperatures rise and populations increase, many cities anticipate that air quality in some locations will exceed the national ambient air quality standards, or that the frequency and duration of such exceedances will increase, which will in turn necessitate increasing emission control requirements on sources that contribute to local air quality problems, with air travel-related emission sources likely to face increased scrutiny.

Other possible climate change implications for airport infrastructure might include (1) higher wind velocities that could damage structures, require tie-downs for larger aircraft, and inundate coastal areas with storm surges; (2) higher average temperatures that could affect material specifications, require longer runway lengths or reduced take-off weights due to compromised aircraft performance, and increase the risk of forest fires; (3) invasive species that could affect landscaping and maintenance practices; and (4) changes in insurance and lending policies that could impact financing costs, public expectations, and the timing and feasibility of airport infrastructure investments.

Consideration of these potential impacts today may be prudent, because preventive planning could produce significant savings should airport facilities require future retrofits. However, airport operators require guidance now concerning appropriate contingency planning. There are not well-developed models or guidelines for reasonable assumptions, scenarios, or projections to use in this type of planning, either at the local, state, national, or global level. Research is needed to aid airports, airlines, FAA, and other stakeholders as they consider the advances and adaptation needed in the air transportation system.

RESEARCH NEEDS

Airports, states, local governments, passengers, companies, and others need adequate tools to conduct local and regional GHG emissions inventories to support informed decision making and transparency. Such tools should be comprehensive, user-friendly, and consistent with each other and with other subnational inventory tools.

Research and debate about the rate of climate change, the human activities that are most responsible, and the human activities that should bear the brunt of required reductions undoubtedly will continue for many years; however, most policymakers and the scientific community generally agree that anthropogenic activities are stimulating climate change throughout the world. The effects of climate change are measurable today in certain parts of the world and are anticipated to further materialize over the course of the next decade.

Because of the initiatives of state and local climate action plans, demands on the air travel industry for GHG emission reductions are likely to increase. Airport operators, which own and control the sources associated with a small percentage of these emissions, will be asked to implement mitigation measures. For instance, the City of Los Angeles' Climate Action Plan mandates a 35% reduction in GHG emissions relative to 1990 levels. Research also would provide better guidance concerning the range of actions that can be undertaken to reduce emissions without adversely affecting the aviation industry.

Building on the current state of knowledge and research into the effects of GHGs on climate change, research into the effects of airports on GHG emissions and into the effects of climate change on airports is needed to inform and support aviation-related policy and decision making. This research will foster a better understanding of the potential trade-offs of any economic, design, technology, or operational control strategies.

Note that many of these questions raise issues that are not unique to aviation or airports. Research should take advantage of information developed for other transportation modes and activities. Specific research topics include the following:

- Follow-up research regarding standardized aviation-related GHG and climate change assessment methodologies for use on a subnational or airport-specific level that are being developed by the ACRP project discussed above.
- Development of consistent, scalable tools to enable the evaluation of air travel-related emissions.
- Identification of anticipated regional climate changes, associated weather patterns, and anticipated timing of such climate change, along with the effects of such changes on aviation and aviation facilities, such as airports.
- Identification of the probable changes in regulatory designations under the Clean Air Act to account for GHGs and the probable effects of future regulations on local air quality and GHG mitigation strategies.
- Identification of the effects of changes in population patterns as a result of climate change and how the changed population patterns might affect demand for air travel.
- The anticipated effect of climate change on airport operations, such as instrument flight rules versus visual flight rules, take-off weight limitations, reliance on satellite navigation, and changes in capacity and aircraft separation.
- The anticipated effect of climate change on the operations at the top 25 air carrier airports and on the national airspace system (NAS), including research into changes in the reliability of the NAS and aviation compared to current day conditions.
- Identification of airport infrastructure that would be affected by predicted regional effects of climate change, such as changes in precipitation volume, frequency, type, and intensity; changes in temperature gradients and wind velocities; changes in vegetation cover and habitat; and changes in the habits of aviation system users. This would include storm water management, snow clearing and storage, airfield and aircraft deicing, runway length requirements, aircraft tie-downs, and ground-cover management, such as requirements for dust control and wildfire management.
- Research into technologies, airport layouts, and operational approaches that would reduce GHG emissions from aircraft and nonaircraft sources at airports.
- Research into increased use of alternative methods in airport construction to reduce GHG generation, and consideration of the ability of alternative pavement materials to withstand possible effects associated with climate change.
- The monetary value of potential aviation-related climate effects for use in assessing trade-offs and market-based measures.

REFERENCES

J. Penner, et al., *IPCC: Aviation and Global Atmosphere*, Intergovernmental Panel on Climate Change, 1999.

City of Aspen, *Aspen Greenhouse Gas Emissions 2004 for the City of Aspen's Canary Initiative,* Climate Mitigation Services for the City of Aspen, January 2006.

City of Seattle, *Inventory and Report: Seattle's Greenhouse Gas Emissions*, September 2002.

City and County of Denver, *Greenhouse Gas Inventory for the City and County of Denver*, May 2007.

County of Sacramento Department of Environmental Review and Assessment; *Final Environmental Impact Report, Sacramento International Airport Master;* July 2007.

FAA, *Capacity Needs in the National Airspace System 2007-2025: An Analysis of Airports and Metropolitan Area Demand and Operational Capacity in the Future*, FAA, May 2007.

ICF Consulting, *The Potential Impacts of Global Sea Level Rise on Transportation Infrastructure Phase 1—Final Report: the District of Columbia, Maryland, North Carolina and Virginia*, December 2007.

Port of Seattle, *Seattle-Tacoma International Airport Greenhouse Gas Inventory—2006*, Synergy Consultants, October 2007.

San Diego County Regional Airport Authority*, Draft EIR Airport Master Plan San Diego International Airport*, October 2007.

University of Colorado Denver, City and County of Denver, Department of Environmental Health; *Greenhouse Gas Inventory for the City and County of Denver*, May 2007.

U.S. Department of Transportation, Climate Change Science Project, Product 4.7, *Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study,* February 2008.

USEPA*, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2005*, USEPA #430-R-07-002, April 15, 2007, available at www.epa.gov/climatechange/emissions/usinventoryreport.html.

U.S. General Accounting Office, *Environment: Aviation's Effects on the Global Atmosphere Are Potentially Significant and Expected to Grow*; GAO/RCED-00-57, Feb. 2000.

U.S. Global Change Research Program, *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change*, 2001; available at www.usgcrp.gov/usgcrp/Library/nationalassessment/foundation.htm.

Water Quality

RICHARD S. DAVIS
Beveridge & Diamond, PC

CLAUDIO H. TERNIEDEN
Water Environment Research Foundation

The effects of airport operations on water quality have been garnering attention as regulators look beyond the more obvious sources of water pollution, such as end-of-pipe industrial waste discharged into large water bodies, and attempt to address issues such as storm water runoff and non-point sources. Airports, which typically include large expanses of impervious surfaces and host activities that can generate discharges of potential contaminants, such as vehicle and aircraft fueling, maintenance, and deicing, have been subject to the requirements of the Clean Water Act for more than a decade, but the application of these rules to the unique operating environment of airports still is being refined. One challenge has been to identify the range of technologies available to minimize and manage deicing runoff, and then to define the climatological, operational, cost, and other factors that enable or disenable their use at specific airports. More recently, site-specific water quality considerations, such as those resulting in the identification of impaired water bodies and the establishment of total maximum daily loads (TMDLs) for specific pollutants for those water bodies, have added complexity to airport permitting.

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 manufacturers typically consider the precise composition of the additive packages to be proprietary information.
- For historical reasons, many airports are located on or adjacent to large bodies of water. These water bodies, along with associated marshes and other wetlands, often provide habitats 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 2,000 ft or less, within which more than 90% 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 the purpose 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 data become available, we will be better able to generalize about discharges from airports.
- In 2004, the Environmental Protection Agency (EPA) identified airport deicing operations as a candidate for the development of a technology-based effluent limitations guideline (ELG). Data collection for this effort, including questionnaires directed to key industry sectors and site visits to airports, was commenced by EPA in 2005 and continued through 2007. The agency estimated that this evaluation would result in a proposed regulatory action by June 2009. That action could be in the form of a proposed ELG containing numeric limitations, best management practices, or no limitations for some or all industry subcategories. In the meantime, some states have set a variety of numerical limits for individual permits.
- The Society of Automotive Engineers (SAE) Aerospace Division has developed and adopted standards limiting the aquatic toxicity of new formulations of Type I aircraft deicing fluids. SAE remains open to the possibility of increasing the stringency of those standards and also may be open to the imposition of similar environmental performance standards for other types of aircraft deicers and for pavement deicing products.
- Airport Cooperative Research Program projects have been developed to provide information on existing pollution prevention and control technologies, on the formulation and potential improvement of deicing fluids, and on the rate of use and potential reductions in the rate of use of deicing fluids consistent with the overriding consideration of flight safety.
- 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. Because 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. Bio-assays 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.
- The Federal Aviation Administration (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.

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.

- 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.

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.
- Further research related to the minimization and management of airport deicing runoff, including research on the impact of changing climatological conditions on airport infrastructure and the efficacy in cold weather of current biological treatment systems.
- 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 following:

- 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 a study of potential adverse effects of new agents on operations and equipment, such as the corrosivity of potassium formate and 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 habitats 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.

REFERENCES

FAA website: www.faa.gov/arp/environmental/5054a/wildhazmou.pdf.
U.S. Government Printing Office, Executive Order 13186, 66 Federal Register 3853, January 17, 2001.
EPA website: www.epa.gov/ost/guide/airport/index.html.

Aviation Alternative Fuels Development and Deployment

RICHARD L. ALTMAN
Commercial Aviation Alternative Fuels Initiative

Propelled by a combination of supply stability, security, and environmental concerns, commercial aviation has sharpened its focus on alternative fuels for aviation over the past two years. In developing and adopting new fuels, aviation encounters unique safety, operational, and environmental challenges. Issues associated with the broad range of aircraft operating conditions constrain the number of candidates to be examined in ways not experienced by other transportation modes. Operating at multiple altitudes presents multiple, and in some cases contradictory, directions to define the best environmental footprint. Any alternative fuel also faces large costs in creating feedstock, production, and distribution infrastructure. In the case of aviation, a unique airport-based infrastructure differs from other transportation modes. While aviation fuels produce unique technical challenges, aviation also must cope with the fact that it represents less than 10% of transportation fuel consumption and hence is seen as a minority player to energy suppliers.

Security issues can be quantified by identifying the magnitude of expenditures needed to defend oil fields, well heads, pipe lines, and sea lanes that are required to protect the two-thirds of domestic needs currently obtained from offshore sources. According to Department of Defense (DoD) sources, this cost is as high as $50 billion to $130 billion annually, without accounting for any costs associated with the war in Iraq.

Supply stability issues go beyond average price. These can be observed as both the frequency of price spikes and the magnitude of refiner's price differential between the price of crude oil and refined aviation fuel, known as the aviation crack spread. Information presented by the Air Transport Association illustrates that crack spread for aviation fuel has tripled over the past few years. Localized price spikes also are more prevalent and include, but go beyond, Hurricane Katrina-like events in the Gulf of Mexico.

The emergence of alternative fuels for aviation adds three additional dimensions to emissions assessments. This comes on top of the consideration of variances already seen in having to evaluate emission effects at varying altitudes ranging from local air quality around airports below 3,000 ft to issues of contrail formation at the upper reaches of the flight envelope.

First, modifications to the fuel content itself will alter outcomes predicted by such tools as the Emissions Dispersion Modeling System (EDMS). These will vary with fuel type. Second, local air quality issues governed by the Clean Air Act may well be impacted. As an example, the initial fuels from synthetic paraffinic kerosene (SPK) are extremely low in sulfur content. This in turn lessens small particulate matter ($PM_{2.5}$) and can have a significant health benefit. The third dimension introduced by alternative fuel consideration is increased attention to changes in environmental life cycle, or "well-to-wing" factors. Alternative fuels may burn cleanly on the aircraft but add to overall emissions in their production and distribution processes.

These considerations include the need to capture and either utilize carbon dioxide (CO_2) via enhanced oil recovery or recycling, or store it permanently in the ground or in saline aquifers when such sources as nonrenewable coal or shale oil are used. Energy balance must also be considered along with land use, and water issues when biofuel crops are harvested. Lastly, the management of byproducts of the fuels themselves can mitigate the need for energy to be used directly to produce those products.

From a safety and operations perspective, aviation fuel, whether Jet A for commercial operations or its nearly identical military variant, JP8, differs from other transportation fuels in its strict requirements for safe operation over broad ranges of temperature and pressure. For these reasons, jet aviation must exclude the use of many current fuels used for ground transportation, such as ethanol. The use of other fuels that vary significantly in volume and density from current aviation fuels operating under American Society for Testing and Materials (ASTM) approved specifications (D-1655) would dramatically alter aircraft payload range characteristics for existing aircraft or require radical new aircraft designs and infrastructure at airports. The costs to make this transition for aviation could far exceed equipment and infrastructure costs associated with other transportation modes.

Given the limitations in specific energy required to accommodate current jet aircraft, for the foreseeable future, practical alternative fuels for aviation are limited to liquids that meet drop-in requirements. Most commonly discussed of these are the following:

- Nonrenewable and renewable SPK fuels. These may take the form of natural gas-to-liquid (GTL), coal-to-liquid (CTL), biomass-to-liquid (BTL), or any combination of the above, frequently called XTL.
- Hydrotreated Renewable Jet (HRJ) from a variety of sources ranging from current feedstocks, such as Jatropha, to algae in the longer term. This category could also include animal fat residues in the mid-term.
- Sustainable aviation biofuel from alternative processes such as fermentation and pyrolysis (in the mid-term to far term).

Fuels that depart widely from the D-1655 density–volume norms (non–drop-in fuels) do not presently have a path to either qualification and certification or practical applications in current aircraft designs for the foreseeable future. Hence fuels of this type (such as hydrogen) are not addressed in this paper.

Resource availability owing to the challenges of infrastructure development will ultimately govern which of the candidates are commercialized and the sites at which developments can take place. Prime in these considerations will be the match in scale between fuel production and the relatively concentrated nature of aviation fueling stations compared to other modes of transportation. For example, economies of scale for Fischer Tropsch (FT) CTL are achieved when production approaches 30,000 barrels per day. Sources of data on BTL production based on a variety of agricultural crops suggest that plant size may optimize at one-tenth that size.

Those considerations are significant when the fuel will need to be supplied to a centralized location such as Chicago O’Hare International Airport, where consumption may range from 5 to 100 times the supply available from any given plant. In the case of renewable fuels, the continuing availability and shelf-life of the feedstock also are critical.

Last, as a consumer of less than 10% of the transportation fuel used in the United States, aviation is hard-pressed to be a first mover in the quest for alternative fuels for transportation in the eyes of energy suppliers. The combination of issues described above requires that aviation interests hone the definition of their alternative fuel needs, develop the data needed to make the pursuit of aviation alternative fuels low risk (both technically and economically for potential suppliers), and agree and communicate clearly and concisely with the fuel supply chain what their requirements are.

The focus areas in which aviation needs to act fall into four fundamental disciplines:

- Research and Development—including initial demonstration of equipment compatibility to accepted risk management principles to achieve acceptable development and deployment risk.
- Certification and Qualification—to ensure the highest level of safe operation while preserving the mission of the vehicle.
- Environmental—to include both the measurement of outputs and the creation of life-cycle modeling tools for both greenhouse gases and current local air quality constraints for which the United States has developed state implementation plans under the Clean Air Act and National Ambient Air Quality Standards for $PM_{2.5}$.
- Business and Economics—includes issues associated with production of fuels that in some cases require additional production processes (hydrogenation of certain biofuels, for example), and distribution unique to aviation's airport-based fueling systems. These issues include both high nonrecurring costs in the case of FT systems and potentially noncompetitive recurring costs in the case of some biofuels, specifically when compared to biodiesels that may command a pricing premium for high cetane rated fuels.

CURRENT STATE

The current state of research in each of the four areas in each of the disciplines above can be described for each of the three candidate fuel types as follows.

Research and Development

Nonrenewable sources of SPK fuels have largely emerged from the research and development (R&D) phase and entered certification and qualification testing. Flight testings of GTL candidate U.S. Air Force (USAF) B-52, 50/50 blend (2006), C-17 (2007), Airbus A-380 (2008), and CTL candidate Sasol (100% South African Airways 747) represent full-scale demonstrations.

Blended biomass and CTL fuels will depend more on the suitability of gasification technology for biomass gasification and co-firing of biomass and coal or other nonrenewables. Industry sources suggest that this experience is limited and largely from foreign sources.

The creation of hydrotreated renewable jet (HRJ) or other fuels using similar processes with varying feedstocks is in the research phase. Significant research is being executed by the Defense Advanced Research Projects Agency (DARPA) with three contractors and by the Boeing Company. In the latter case this has led to flight testing in 2008 on at least two platforms: a Boeing/General Electric/Virgin Atlantic 747 and a Boeing/Rolls Royce/Air New Zealand 747. Testing by Boeing on a 737 platform (with Continental Airlines and CFM International engines) and a 747 (with Japan Airlines and Pratt & Whitney engines) is planned.

Longer-term aviation biofuel from algae oil sources appears to have the highest potential yield per acre: as much as 100 times that of soybeans. That work is the subject of a 2008 research solicitation by DARPA.

Certification and Qualification

A critical threshold was passed during 2005 with the adoption of protocols detailing generally accepted procedures for the approval of alternative aviation fuels by original equipment manufacturers of engines. These methods attack the most time-consuming core technical tasks involved in approving fuels and promise to radically reduce both the cost and cycle time for qualifying (in the military, certifying) these fuels. Coupled with the increased levels of military and civilian investment in R&D, definitive plans are now in place.

As of this writing, a proposed 50/50 generic certification modification to D-1655 to permit approval of the full spectrum of fuels now characterized as SPK from a variety of nonrenewable (e.g. coal and gas) to renewable (e.g., cellulosic biomass and animal fats) is planned for ASTM balloting for subsequent review at a joint meeting.

Because SPK fuel blends will be inherently low in sulfur, it is necessary to execute activities to research thresholds to which sulfur content can be reduced without incurring significant penalties in engine component life owing to reduced lubricity. To ensure that this work is done in a timely manner and that all factors (most significantly reduced particle formation) are accounted for, the Federal Aviation Administration's (FAA) Office of Environment and Energy has funded efforts within the research arm of the ASTM to provide needed cost–benefit data by the end of 2009, which may help lead to certification of pure, 100% SPK fuel blends in 2010.

Bio–Jet Fuel Certification

Certification of bio–jet fuels from such feedstocks as first-generation hydrotreated vegetable oils is now more accurately called hydrotreated renewable jet (HRJ) fuel. The category includes algae-based initiatives and depends on successful outcomes of research now being conducted intensively by agencies such as DARPA. Those results will be completed with subsequent "fit for purpose" testing funded by the Air Force Research Laboratory (AFRL) now underway. Dependent on a positive outcome of DARPA–AFRL testing of hydrotreated oils, qualification of those fuels as a blend, at a percentage level to be determined on the basis of those tests, could occur as early as 2010. Certification of 100% HRJ could come as early as 2013 if the 2010 hurdle is met.

Environmental

Efforts concentrate on both measurement and building models to assess life-cycle costs for a full range of fuel types. However, the use of these tools to assess system capacity under the range of NextGen traffic projections has yet to be evaluated using this information.

Measurements for emissions content were originally achieved on a T-56 engine type. Subsequent assessments of outcomes from B-52 aircraft testing of 50/50 GTL fuel and 100% CTL fuels on an engine rig were presented at the Commercial Aviation Alternative Fuels Initiative (CAAFI) 2007 annual meeting. Those measurements have been broadly disseminated. Emissions measurements of biofuel candidates to the standards set by the FAA Office of Environment and Energy began in the fall of 2007. Additional measurements are anticipated on a NASA test bed in 2008 on the candidate fuels flight tested. The conclusion that candidate SPK fuels have significant reductions in sulfur and PM 2.5 is an outcome of the initial testing.

To date, modeling is concentrating in three specific areas and is tied to FAA's EDMS for emissions prediction at airports and Aviation Environmental Portfolio Management Tool (APMT) for total cost–benefit, including health effect costs. Not included is any specific assessment of the ability to achieve levels of sequestration. Rather, the range of sequestration outcomes is considered an independent variable.

FAA's Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER) Center of Excellence (COE) has completed an initial "well-to-wake" life-cycle assessment of some 11 alternative fuel candidates. The study, not formally released as of this writing, adapts emissions predictions in the production processes from Argonne National Lab's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model. GREET models specifically adapted to jet fuel affect accuracy in current studies.

As part of the PARTNER well-to-wake evaluation, a specific modeling example of the effects of sulfur removal was conducted in FAA's APMT and documented in presentations to the International Civil Aviation Organization's Committee on Aviation Environmental Protection in the fall of 2007.

In the interest of easing the calculation of both financial and environmental cost–benefit, ACRP has initiated a project titled *Handbook for Analyzing the Costs and Benefits of Alternative Turbine Engine Fuels at Airports* (ACRP Project 02-07) for use by airports, airport consultants, and energy companies to assess the effects of introducing alternative fuels to airports. One potential benefit of such introduction is allowing for aircraft and ground support equipment (GSE) to utilize the same fuel. Currently GSE is limited to using low-sulfur fuels similar to those that may emerge from certification efforts described above.

In an effort to restrict the discussion to aviation-specific issues, issues of carbon sequestration that are common to all energy production were excluded from the current state, along with market-based mechanisms for carbon management, such as cap-and-trade schemes.

Business and Economics

To date, studies of alternative fuel economics have focused studies on the economics of introducing alternative fuels at airports as described above, and assessments of the overall economics of fuel production. Predictions of how much fuel could be available in the near term from various sources, and what the costs of these options are in dollars per barrel equivalent crude, are available from at least several sources, two of which are definitive and generally available. Other publications provide an inventory of plant construction. Specifically available resources of significant value to researchers include the following:

- Plans for the construction of both FT nonrenewable and combined CTL–BTL plants are published on a regular basis by the Department of Energy (DOE). Approximately 14 plants are on the drawing board in the United States. Ten times that number of plants are planned to be constructed outside the United States.
- The economics of CTL plants have been researched and well documented in studies by Scully Financial under contract to DOE, USAF, and the Environmental Protection Agency (EPA). Viable production pricing of \$55 to \$60 dollars a barrel was projected in the 2006 to 2007 time period, including carbon capture (but not sequestration) for plants of 30,000 barrels per day or larger. More recent studies have been executed by both Noblis and DOE's National Energy Technology Lab for biofuel–coal to liquid (CBTL) plants. Prices are higher in the later

studies commensurate with increases in commodity costs for plant construction, feedstock costs for biomass in particular, and feedstock transportation costs. They remain, however, in price ranges encountered for oil-derived fuels in the same time period.

- A case study of a similarly sized plant situated in South Central Illinois using a combination of coal and biomass feedstock (CBTL) was the subject of a study performed by Princeton University and presented to the FAA's PARTNER COE Carbon Sequestration Workshop. The study concludes that similar fuel costs are theoretically achievable with biomass contributions from switchgrass offering 20% of the total. When combining the life-cycle benefits of 20% biomass and employing carbon sequestration, the fuel production can have a carbon-neutral footprint. The cost of biomass to obtain carbon neutrality with an approach desirable to crop producers is on the order of $100 per ton.
- While yet to be formally published, an overview of outcomes of the fiscal 2007 FAA-funded studies of near-term availability of various fuel types was presented at the 2008 Transportation Research Board Annual Meeting. Those studies suggest that while all production options in the near term are severely limited, 10 times the production amounts of FT fuels are likely, compared to most biofuel sources.

Other business considerations were discussed in various forums during the course of 2007. These include matching production sources with the need for the unique, consolidated fuel distribution at airports, and the percent of alternative fuel production that typically will be available to jet fuel as opposed to motor fuels. Technologies to reduce plant and equipment costs are a key to the feasibility of economic fuel production. In addition, issues associated with the need to reduce water use and find ways of using dirty water in production for both renewable and nonrenewable fuels have become prominent.

Market factors include the effects of competition for fuel with other sources (high cetane users) and the patchwork of tax incentives in many cases not available to aviation producers and users, as well as the absence of data on the current database of fuel supply at airports. As a minority user with just 8% of transportation fuel, aviation's ability to be a first mover is vital in shaping production and distribution systems for fuels and users' influence with suppliers. Specifically:

- Biodiesel Plant Size—Factors influencing biodiesel costs and limiting plant size are cited as labor and travel optimization. In general, typical agricultural crops from farmlands optimize at plant sizes of 3,000 barrels per day. This size is approximately one-tenth the size of economic CTL plants. The low scale of biodiesel plants is an issue in that large airports such as Chicago O'Hare may require as many as 30 such plants in proximity to pipelines supplying the airport, given airport distribution system infrastructure.
- Algae Production Optimization—While it has the potential to produce 100 times the yield of crops compared to soy crops, efforts to optimize algae production are a major research theme of DARPA's algae project, for which proposals have been solicited.
- Aviation Fuel Yields from Production Facilities—Energy companies cite typical optimized aviation fuel yields of 20% of full plant production for a FT plant. The economics leading to this practice may need to be addressed if fuel availability at reasonable quantities is to be achieved.
- Aerospace Technologies to Increase Quality Decrease Cost of Production—Aerospace technologies may have significant impacts on the acquisition and operating costs of

such products as gasifiers. One such example is the use of rocket-based gasification technology. This technology has yet to be demonstrated in large scale but potentially could drive down FT production costs.

- Water Quality and Availability Drivers for Cost—A significant concern is the scarcity and quality of water that impacts both renewable and nonrenewable fuel production. In the case of renewable fuels the current difficulty of growing crops in saline or poor quality water was viewed as a limitation on renewable fuels that drives prices up. Similarly the availability of water for cooling FT plants is viewed as a likely cost driver for those facilities.
- Competition from High Cetane Users—This issue has been cited as a disincentive to aviation fuel production. Currently diesel fuel users are willing to pay a premium for high-performance fuels that aviation fuel users typically will not. In addition, aviation fuels may carry additional production costs—added hydrogenation, for example—to meet aviation fuel specifications.
- Tax Incentives and Disincentives—While tax incentives are available to ethanol buyers, they typically are not available to aviation fuels. It appears that this issue for both nonrenewable CTL and renewable biodiesel and jet fuel has been addressed in congressional action tied to the financial crisis. In some cases, however, tax policies may be a deterrent to low-sulfur fuel production as GSE fuels and aircraft fuels are taxed differently.
- Availability of Database on Fuel Supply—If energy suppliers are to seek to access airport fuel supplies, they must first know the current state of supply.
- Aviation as a First Mover—USAF has sought to position aviation as a first mover in establishing specific consumption targets into the next decade. Outcomes of the CAAFI annual meeting in November 2007 have prompted evaluations by the airlines of how to achieve similar demand to encourage production.

FUTURE VISION

- Increase Supply Security—Production levels of alternative fuels should increase rapidly so that aviation fuels from domestic sources can supplement petroleum supply by some certain date, and as early as the Southern States Energy Board goal of 2030. In parallel, supply security needs to be embraced and a broad range of alternatives should be employed.
- Assure Competitive Price and Price Stability—Minimal price fluctuations owing to localized disruptions in supply should be enabled along with a return to historical levels of crack spreads for aviation fuels ($5 order of magnitude) and elimination of the need to tanker fuel (i.e., carrying more fuel on-board than is necessary for the flight and buying less higher-priced fuel along the route of flight) as a result of disruption.
- Fuel Supplies Available to Support Next Generation Air Transportation System (NextGen) Traffic Projections—Alternative growth scenarios suggesting two-three times movement accommodated in both quantity and distribution systems are needed, so long as fuel availability does not limit growth or dictate growth patterns.
- Quantify and Accept Environmental Gains—Long-term gains will require continuous reductions of greenhouse gas and local air quality factors as a result of the adoption of alternative fuels. Carbon-neutral solutions should be sought in the long term but do not compromise localized air quality in doing so. Life-cycle emissions are calculated using aviation-specific production algorithms and not approximations from calculations formulated for other similar

fuels. In the nearer term, gains in the process to calibrate and calculate greenhouse gas on a life-cycle basis should be universally accepted from any new fuel that is introduced.

- Improve Safety and Operability—Better thermal properties and broadened usage beyond the aircraft should be feasible and will facilitate movement toward alternatives.
- Implementation of the *Handbook for Analyzing the Costs and Benefits of Alternative Turbine Engine Fuels at Airports* (ACRP Project 02-07)—The ACRP handbook should be used globally to increase the use of Jet A/JP-8 alternatives. In addition, data documenting the current state of fuel supply at all airports should be available.
- Qualify or Certify Alternative Fuels of Various Types—Fuels that are fully interchangeable and indistinguishable in meeting airline operating requirements need to be approved to allow local sources of supply to prosper independently of feedstock choice.

Aviation needs to be a first mover for alternative fuels suppliers, owing to its ability to communicate and align behind data-driven solutions globally and achieving the prior elements of this vision.

RESEARCH NEEDS

Many recent actions have been taken to encourage the development and flight demonstration of a wide range of synthetic and alternative fuels. Research steps that will expedite the deployment of alternative fuels are either in the early stages or do not exist, particularly for renewables. In particular, cost reductions to improve the attractiveness of investment to financial sources need to be demonstrated and proved reliable in production scale for all fuels. While environmental tools exist, they need to be widely applied and directed to the full range of potential production options. The existence of needed data to expedite timely certification is critical to success.

Overall, research needs to embrace the concept that there is no one answer to alternative fuels supplies, but rather the future will be built from a wide variety of options: silver buckshot, rather than a silver bullet approach. Other key steps have yet to begin. The following are initiatives that either have been identified as gaps or as ones that will be required as follow-up:

- R&D on hydrotreated renewable jet and other renewable sources ensures the attainment of certifiable fuel properties; thus pilot plant production capability to amounts in excess of 250,000 gallons will be required to allow tests in multiple combustor types including rich burn, lean burn, and afterburner configurations for this purpose.
- In the case of BTL, key efforts remain to demonstrate that gasification via co-fired or separate gasifiers can achieve high performance and reliability standards. Other technologies to reduce cost and improve durability are required.
- Technology demonstration of full systems to optimize and broaden water usage (more saline, poorer quality) is required to ensure that energy facilities do not compete with water for food crops and human and livestock consumption.
- To ensure that certification is achieved expeditiously for all fuels, issues that may exist in the use of any fuels (fit for purpose) should be dimensioned early by the Coordinating Research Council or other research arms to ensure that they are not the critical path in fuel approval.
- Long-term durability on any new process is subject to a series of unknowns, many of which likely will not have been envisioned. Questions about the effects of seal swelling

characteristics (reduced sulfur fuels) and altered lubricity characteristics suggest the need for lead-the-fleet type extended durability on fuels that go into service. Durability issues, while not evident from the data available, could affect airport fuel handling (filtration and storage). Hence, efforts should extend to the facility level.

- Research to eliminate uncertainties in pipeline distribution of biofuels (such as water hiding) needs to be undertaken. The aviation fuel supply will depend not only on production, but also on the economics of use.
- In the case of all research, technical criteria emerging from DoD and the National Aeronautics and Space Administration risk management systems should be utilized to ensure investor confidence in new solutions. Government participation to ensure that these technologies meet technology readiness level 5 criteria (production scale-up), in particular, is critical.
- The realization that there is no one single answer to feedstock and production processes for supplying alternative aviation fuels is a final research requirement. Accepting this silver buckshot concept requires investment in tools to instruct us how to optimize production solutions to available resources as a key to both economic and environmental goals.
- On the macro level, a scenario analysis considering optimized production scenarios for a matrix of Jet A, nonrenewable, and renewable fuels, coupled with the range of NextGen traffic forecasts and agreed-upon fuel usage growth, will both assist in the assessment of suppliers' ability to meet system needs and provide a realistic assessment of what is achievable in terms of aviation emissions.
- A tool kit to provide states and local investors with a means of assessing their ability to arrive at viable solutions combining any of the three production options with available resources would be an extremely valuable aid to streamlining implementation efforts.

REFERENCES

Numerous references cited in this paper are documented in the Commercial Aviation Alternative Fuels Initiative Knowledge Sharing Network password-protected website. They are available upon request on individual subjects from the author, CAAFI Executive Director Richard Altman (altrich@cox.net), or CAAFI Deputy Executive Director Nathan Brown (Nathan.brown@faa.gov).

Sustainability

CHERYL KOSHUTA
Weston Solutions, Inc.

CAROL LURIE
Vanasse Hangen Grustlin, Inc.

BURR STEWART
Port of Seattle

One cannot open a newspaper, read an aviation industry publication, or hear a television or radio broadcast without the concept of "sustainability" being mentioned. Sustainability has captured the attention of both the public and the business world. Although the term has been used in European and other international markets for many years, it has only recently become a common term in the United States. Many people within the aviation industry have embraced it as a way of doing business and have made great progress, while others are still puzzled by what the term means, or they fear that it is the cloak of another anti-growth movement that will negatively impact their businesses. This disparate understanding and implementation is a critical issue that calls for increased education, information sharing, and research.

There are many definitions of sustainability, one of the most famous being the Brundtland Commission definition of "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." These needs usually are grouped in three broad categories: economic, social, and environmental. Several metaphors are used to illustrate the need to balance and tradeoff between these categories of needs. The "triple bottom line" often is used in the business context to show performance metrics, not only for the traditional financial bottom line, but also for environmental and social bottom lines. The "three-legged stool" metaphor shows that the three legs of economy, equity, and environment all must be equal to support the confluence of the three in the seat of the stool as sustainability. The "wedding cake" metaphor shows that a healthy economy depends on a healthy society, which in turn depends on a healthy environment. The common theme is that any one of these broad categories of needs cannot be ignored or exploited if the enterprise is to be successful for the longterm.

CRITICAL ISSUES

For the aviation industry, the term "sustainability" immediately raises several questions: What is the driver for sustainability: climate change, environmental impact, social or economic necessity, or the cost of fuel? What is to be sustained: the global economy, the aviation industry, an airport, the environment, or the community? What areas are we considering: the airports, the entire trip from take-off to landing, or the market area that an airport serves? Who takes responsibility for sustainability actions: airports, air carriers, customers, or regulators?

The tools and methods of managing the sustainability of complex systems are beginning to be developed, and applied to aviation. Transparency is a broad set of communication tools to make the various and complex trade-offs increasingly visible to the stakeholders of sustainability strategies. Life-cycle analysis is a methodology for evaluating the benefits and costs of a project for the entire time of its useful life, taking upfront planning and construction costs into account, balanced against operational and environmental or other costs for the useful life of a project or facility. Scenario planning is a method for forecasting a variety of possible long-range futures and developing plans for an enterprise that are resilient in adapting to a variety of possible scenarios. Asset management systems keep track of an organization's entire portfolio of assets and their relative risk and value to the system. Systems dynamics models are computer simulation programs that can evaluate very complex system interdependencies in multiple future scenarios. Developing effective applications of these tools in aviation is a critical research need.

The policy challenges raised by sustainability for aviation are critical. There are the challenges of the aircraft manufacturers as they deal with engine emission controls and the development of alternative fuels. The airlines share in that challenge but also face the issue of serving the public while struggling to make a profit with their existing fleet of aircraft. There are different challenges for airports, including economic development, noise, pollution, and traffic. Airport tenants, concessionaires, cargo handlers, and the traveling public have another set of challenges. There is a critical need for effective policy analysis on all of these topics.

The impact of aviation on climate will be a critical driver on the journey to sustainability. Aviation is the only mode of transportation that does not have alternative (non-carbon-based) propulsion technologies available.

The following are key critical issues associated with sustainability and aviation:

- What role does aviation play in the sustainability of metropolitan regions and countries?
- What path can aviation take to phase out the use of fossil fuels?
- What criteria can be used to assess performance in pursuit of sustainability?
- What shared tools will help the aviation industry advance its sustainability?
- What is an effective framework for making trade-offs among, and valuing, the triple bottom lines?
- Can aviation be conducted in a way that protects the environment, does not adversely impact communities around airports, and still be profitable?
- What strategies can help aviation organizations and users to rapidly adapt to increasing stakeholder pressures regarding sustainability, from local to global?

CURRENT STATE

Many organizations in the aviation industry are addressing the issue of sustainability and are devising their own metrics and reporting systems. Best practices include the use of sustainable design standards such as the U.S. Green Building Council's Leadership in Environment and Energy Design accreditation program for built facilities; the Global Reporting Initiative that disseminates globally applicable sustainability reporting guidelines for voluntary use by organizations reporting on their economic, social, and environmental conditions; and International Organization for Standardization 14001:2004, which establishes the requirements for environmental management systems (EMSs), confirming a global standard for organizations wishing to operate in an environmentally sustainable manner.

In response to federal, state, or local mandates for implementing sustainable practices, airport managers are forming "green teams" to develop strategies for reducing the net impact of operations. Organizations are conducting greenhouse gas emissions inventories and developing programs to deal with the issue. EMSs are being used to set goals, institutionalize best practices, and track environmental information and performance. In some cases, those EMSs are evolving into sustainability management systems to track triple-bottom-line performance. Some of these programs and best practices are shared on an industry website, www.sustainableaviation.org. Despite efforts by the aviation industry interest groups, there is not yet a single, accepted aviation sustainability standard that benchmarks progress and provides a comparable basis for measurement of success.

There are many options to be considered in every decision that is made. There is no common metric or measure to determine if any segment of the industry is becoming more sustainable. In other words, it is impossible to do comparisons of activities or of airports or of businesses. This is not unique to the aviation industry.

Moreover, most entities in the United States continue to focus disproportionately on the environmental aspects of sustainability, while continuing to employ financial metrics that are very traditional and short-term as opposed to life-cycle and long-term. Social and community aspects are generally considered separately, without attempts to integrate them into basic decision making, and programs dealing with the social aspects of employee relations are also considered separately, despite research that shows employee recruitment and retention are tied to a business' reputation as it pertains to sustainability. Although there has been much written on the concept of sustainability, specific applications to the aviation industry have been lacking.

FUTURE VISION

The vision for the future is that there would be a common understanding of the concept of sustainability among businesses, governmental entities, and the public, understood by the aviation sectors. There will be an accepted system or standard for measuring sustainability efforts within the aviation industry that promotes creativity and recognizes differences among participants. There will be mechanisms for both self-reporting and independent third-party verification of the application of the standard to an entity. There will be a global reporting system for the aviation industry that takes data from local entities and consolidates it into national and global data structures.

Research will continue on all environmental fronts for solutions with less impact on, and possibly improvement to, the environment. Research will continue on community and social implications of decisions, and it will factor equally with environmental and fiscal considerations.

RESEARCH NEEDS

- Research regarding integrated intermodal transportation systems to maximize fuel and energy efficiency and consideration of overall environmental, social, and economic impacts.
- Development of aviation industry standards for sustainability, including common metrics for comparison within and between organizations.

- Research regarding the relative role and contribution of aviation access to the economic, social, and environmental development of both the various regions of the United States (including urban and rural) and developed and developing countries.
- Synthesis of sustainability practices by airport operators, airports, airlines, airport tenants, and concessionaires.
- Synthesis of U.S. federal, state, and local regulations, mandates, and executive orders that require airports to adopt sustainable practices.
- Compilation of tools currently being used to implement sustainable solutions.
- Sharing of best practices worldwide.
- Development of automated collaboration methods for collecting, updating, tracking, and visualizing system performance data.
- Research on how to best apply life-cycle cost analysis to the aviation industry and businesses within it.
- Development of information technology to allow mining of data for life-cycle cost product information.
- Development of technical information regarding sustainable environmental solutions.

REFERENCES

Brundtland Report, *Our Common Future,* www.un-documents.net/wced-ocf.htm.
www.epa.gov/Sustainability/.
www.iata.org/whatwedo/environment/sustainability.htm.
www.sustainableaviation.org.
www.unep.org.

Environmental Review Process

John E. Putnam
Kaplan Kirsch & Rockwell, LLP

Consideration of environmental issues at airports is a complex and often inefficient process, both in terms of environmental documentation for proposed development and of ensuring that airport operations meet applicable regulatory, policy, and other requirements. Protracted environmental documentation can 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 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, management, 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, management, compliance, rulemaking, and enforcement roles are shared among entities at the federal, state, and local levels: airport owners; the Federal Aviation Administration (FAA), Environmental Protection Agency, Army Corps of Engineers, and Fish and Wildlife Service; state environmental agencies; airport tenants; and municipalities, for example. 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 pivotal 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, water quality, 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. Increasingly, airports, airlines, and manufacturers also are looking at proactive environmental management or sustainability management approaches to meet business or policy objectives beyond strict compliance. An improved understanding of the strengths and weaknesses of the environmental review, management, and compliance processes associated with aviation is critical.

CURRENT STATE

In the fall of 2000, the aviation industry and Congress gave increased attention to additional capacity at congested airports. Many stakeholders identified environmental processes (the analyses conducted under the National Environmental Policy Act, or NEPA) among the 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 U.S. Department of Transportation (DOT) report to Congress in 2001, *Environmental Review of Airport Projects*, and the U.S. Government Accountability Office 2000 report, *Aviation and the Environment: Airport Operations and Future Growth Present Environmental Challenges*. Industry organizations such as Airports Council International–North America and the American Association of Airport Executives identified proposals to address perceived shortcomings of current processes. Environmental organizations and local governments also have expressed concerns with the manner in which aviation environmental issues are addressed.

FAA has implemented streamlining initiatives identified in the DOT 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 included provisions intended to streamline environmental review for aviation projects in Vision 100, the FAA reauthorization bill for 2004–2007. In 2003, a task force appointed by the President's Council on Environmental Quality (CEQ) issued a report identifying ideas for possible reform of federal environmental reviews: CEQ is implementing some of these ideas and considering others. In June 2004, FAA issued an updated version of its agency-wide guidance on environmental policies and procedures (*Order 1050.1E – Environmental Impacts: Policies and Procedures*). In April 2006, the FAA issued an update to the Airport Environmental Handbook (FAA Order 5050.4B), retitled as *National Environmental Policy Act (NEPA) Implementing Instructions for Airports*. The updated Order 5050.4 was followed in October 2007 with the *Environmental Desk Reference for Airports*, which is intended to provide more detailed and updated guidance regarding environmental review requirements.

In addition to this focus on the environmental review process, there has been an increase in attention to improvements in environmental management. In April 2000, the president issued Executive Order 13148, *Greening the Government Through Leadership in Environmental Management*, which required federal agencies to adopt principles and approaches associated with environmental management systems (EMSs). An EMS is intended to methodically assure that environmental goals and requirements are brought into organizational decision making from top to bottom and to continuously manage environmental issues through a cycle of planning, implementation, data collection, and review for changes—a process known as "Plan, Do, Check, Act." FAA and other stakeholders currently are working to make the EMS a critical guiding concept for the Next Generation Air Transportation System. In addition, other aviation entities have been using EMSs or related concepts to manage environmental issues. For example, at least four airports have secured International Organization for Standardization 14001 certification for all or part of their facilities, and at least three other major airports have developed comprehensive EMSs.

Despite these initiatives, a considerable gap in knowledge regarding aviation-related environmental review and compliance processes remains. 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. In meetings of the Airports Council International–North America (ACI-NA) and the Airport Consultants Council, airport and environmental planners have noted that one of the reasons that the NEPA process can take longer than expected is that timing of project and physical planning is not always well integrated with NEPA processing needs. A group of volunteers from ACI-NA has formed a planning–NEPA integration task force. This group is collaborating to develop a best management practice document to identify lessons learned and recommend actions and issues that should be considered to better integrate the two processes.

Finally, without further analysis, it is unclear whether any of the initiatives that have been undertaken in the past few years relating to environmental review have made significant and lasting improvements in practice. A better understanding of the actual effects of recent initiatives will be important in developing new approaches to the environmental review process.

FUTURE VISION

There is a need to improve the process of conducting environmental reviews, ensuring environmental compliance, and improving the management of environmental issues at airports. This effort will require improved analytic tools, improved systems of environmental management, 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, consideration of alternatives to traditional forms of regulation, and the use of communication 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, management, and compliance processes to better achieve timely development of aviation services and environmental protection. Environmental review, management, and compliance processes should, among other things, (1) inform decision makers and the public of the environmental impacts of projects; (2) support selection and implementation of projects that promote transportation and environmental goals; (3) ensure compliance with environmental requirements; (4) ensure transparency and accountability within and without an organization for environmental requirements or goals; (5) promote attainment of environmental, social, and economic sustainability goals; (6) work within reasonable and predictable timeframes; and (7) minimize costs. 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 in the context of the environmental review of new aviation projects, while others relate primarily to ongoing management of and 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 following:

- Consider the adequacy of current environmental review and management tools for addressing new environmental challenges, such as climate change.
- Determine the amounts of time that environmental review and compliance processes currently require for various airport projects and determine how such timelines vary by project type, regional location, and impacts.
- 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 effects of current and forthcoming streamlining and other measures, as well as the effects of implementing new regulations or guidance.
- Assess the effectiveness of environmental documents in communicating impacts, risk, and complex topics—such as 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.
- Consider the potential relationships between environmental management or sustainability management systems and traditional environmental review processes.
- Evaluate the forecasts, assumptions, and predictions made in previous environmental reviews in light of actual experience.
- Evaluate the use of adaptive management processes in the environmental review of aviation projects.
- 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 (an effort that links with research needs listed in the noise, air quality, water quality, and tools sections).
- List the factors critical to addressing community opposition and concerns.
- Assess the effectiveness of environmental and sustainability 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.
- Evaluate the effectiveness of components of the environmental review process and develop measures to benchmark best practices.

REFERENCES

Council on Environmental Quality, *Compendium of Best Practices*. Posted at http://ceq.eh.doe.gov/ntf/compendium.

Council on Environmental Quality NEPA Task Force, *Modernizing NEPA Implementation,* Sept. 2003. Posted at http:/ceq.eh.doe.gov/ntf/report/finalreport.pdf.

Department of Transportation, *Report to Congress, Environmental Review of Airport Projects*, 2001. Posted at www.faa.gov/airports_airtraffic/airports/resources/publications/reports/index.cfm?sect=environmental.

Executive Order 13148, *Greening the Government Through Leadership in Environmental Management*, April 21, 2000. Posted at http://ceq.eh.doe.gov/nepa/regs/eos/eo13148.html.

Executive Order 13274, *Environmental Stewardship and Transportation Infrastructure Project Reviews.* Sept. 18, 2002. Posted at http://ceq.eh.doe.gov/nepa/regs/eos/eo13274.html.

Federal Aviation Administration, *FAA Guide to the Best Practices for Environmental Impact Statement Management.* 2002 version. Posted at http://faa.gov/.../eis_best_practices/media/EIS_Best_Practices.pdf.

Federal Aviation Administration and National Organization of State Aviation Officials, *Federal and State Coordination of Environmental Reviews of Airport Improvement Programs*, March 2002. Posted at www.nasao.org/Publications/pdf_files/EIS_FAA_NASAO_Report.pdf.

Federal Aviation Administration, *Environmental Management Systems and NEPA Adaptive Management*, May 2004. Posted at www.faa.gov/regulations_policies/policy_guidance/envir_policy/media/WebEMSAdaptive.pdf.

Federal Aviation Administration, Order 5050.4B, April 2006. Posted at www.faa.gov/airports_airtraffic/airports/resources/publications/orders/environmental_5050_4/.

Federal Aviation Administration, Order 1050.1E, June 2004. Change 1. Posted at www.faa.gov/regulations_policies/orders_notices/media/10501ECHG.pdf.

General Accounting Office, *Aviation and the Environment: Airport Operations and Future Growth Present Environmental Challenges*, August 2000. Posted at www.gao.gov/archive/2000/rc00153.pdf.

Aviation Environmental Modeling Tool Suite

Rebecca Cointin
Joseph DiPardo
Mohan Gupta
Ralph Iovinelli
MaryAlice Locke
Lourdes Maurice
Federal Aviation Administration

The adverse environmental by-products of aviation increasingly affect civil aviation's capacity to grow and to operate. Although there are multiple by-products and interdependences that are important to understand, mitigating noise and air pollutant emissions as well as fuel burn (which directly impacts climate), are particularly critical and more directly relevant to aircraft and engines. Delivering technologically and economically feasible decreases in noise, emissions, and fuel burn is a growing challenge. Substantial progress already has been made, particularly in reducing jet engine noise and fuel burn. 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 should employ a mix of source reduction technologies with operational procedures, controls, and land use management. The challenge is to understand the interdependencies between aircraft noise and aviation emissions and among emissions of various air pollutants to optimize mitigation strategies and to minimize environmental impacts as a whole. It also is critical to employ robust cost–benefit analyses to inform decision-making processes. Exploiting continuously increasing computing power will play an important role in achieving that understanding.

Advancement of superior support tools will enable an interdisciplinary approach to assessing aviation environmental impacts and interrelationships. These tools should give decision makers—including the aviation industry, government, and the public—the information they need to develop responsive strategies: cost-effective strategies driven by benefits that allow aviation to grow in an environmentally responsible manner. The aviation industry needs to analyze the interdependencies among noise and emissions in both the design and operating contexts. Government agencies need to assess the consequences of proposed regulatory environmental actions and policy decisions in terms of the effects on noise and air pollutant exposure, as well as the economic consequences. The public needs reliable and clear information on noise and emissions impacts to participate effectively in decision making that could affect public 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 also maintain a state-of-the-art analytical capability to support ongoing needs for aviation noise and emissions analyses.

CURRENT STATE

The Federal Aviation Administration (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 (INM) for singular airport analyses, the Noise Integrated Routing System (NIRS) for regional noise assessment, and the Emissions and Dispersion Modeling System (EDMS) for both singular and regional airport emissions capabilities. FAA also has developed the Model for Assessing Global Exposure to Noise from Transport Aircraft (MAGENTA) for national and global noise assessments, and the System for Assessing Aviation's Global Emissions (SAGE), which estimates aircraft fuel burn and emissions over the entire international and domestic flight regime. The National Aeronautics and Space Administration (NASA) is at the forefront of developing aircraft and engine design and analyses models that also encompass predictive capabilities for noise and emissions. These models include aircraft noise prediction, advanced vehicle performance analysis, and engine performance and mechanical design tools.

Efforts to address aircraft noise and aviation air pollutant emissions issues historically have advanced largely along independent paths, with separate foci, modeling tools, research projects, analyses, metrics, and decisions. As a result, the current legacy analytical tools are inadequate to assess interdependencies between noise and emissions or to analyze the cost and benefit of proposed actions. Over the past few years, the FAA Office of Environment and Energy, in collaboration with Transport Canada, has focused on developing a comprehensive tool suite that allows thorough assessment of the environmental effects and impacts of aviation. This tool suite comprises the Environmental Design Space (EDS), Aviation Environmental Design Tool (AEDT), and Aviation Environmental Portfolio Management Tool (APMT). Once fully mature, this integrated tool suite will be capable of characterizing and quantifying the interdependencies among aviation-related noise and emissions, impacts on health and welfare, and industry and consumer costs and associated environmental benefits under different policy, technology, operational, and market scenarios.

Figure 1 shows a simplified schematic of the new tool suite. EDS is developed to estimate aircraft performance trade-offs for different technology assumptions and policy scenarios. AEDT takes detailed fleet descriptions and flight schedules as input and produces estimates of noise and emissions inventories at global, regional, and local levels. AEDT development leverages FAA's current environmental tools: INM, NIRS, EDMS, MAGENTA, and SAGE. APMT includes both economic and environmental impact analyses capabilities. The APMT economic model takes inputs from different policy and market scenarios, as well as existing and potential new aircraft types (the latter from EDS or other sources). The tool then simulates the behavior of airlines, manufacturers, and consumers, producing a detailed fleet and schedule of flights for each scenario year for input to AEDT. For the environmental impact analyses, APMT takes the outputs from AEDT and performs comprehensive analyses for global climate change, ambient air quality, and community noise impacts. These environmental impacts are quantified using a broad range of metrics including, but not limited to, monetized estimates of human health and welfare impacts, thereby enabling both cost-effectiveness and cost–benefit analyses.

While the legacy basis of these tools is at various stages of development, each area of the tool suite is currently functional for global and national analyses. Tool suite development and

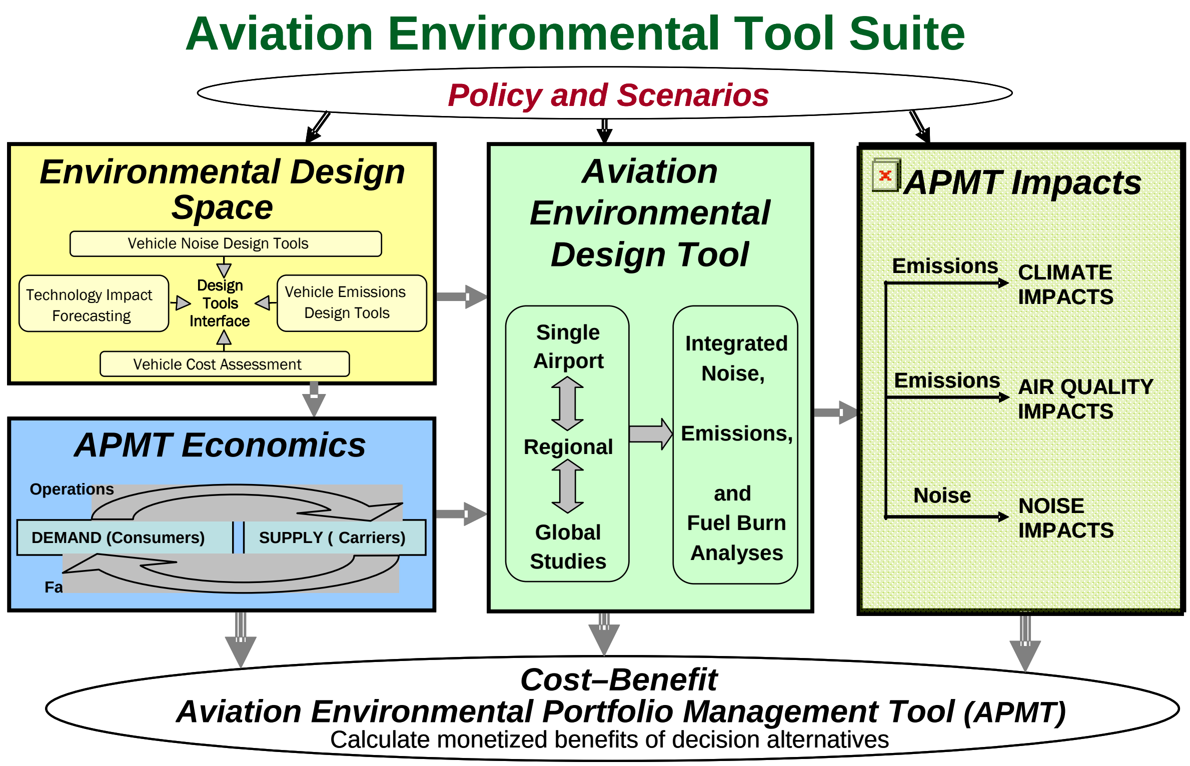

FIGURE 1 Simplified schematic of the FAA Office of Environment and Energy's integrated tools suite currently under development, consisting of the Environmental Design Space, Aviation Environmental Portfolio Management Tool, and Aviation Environmental Design Tool.

the capabilities of its various components have been presented and discussed at four FAA-sponsored Transportation Research Board workshops. Domestic and international aviation sector stakeholders actively participated in these workshops and provided constructive feedback on the development of the tool suite.

A key element of the ongoing tool suite development is the assessment and evaluation relative to fidelity requirements and sensitivities to input assumptions. This assessment is designed to identify possible gaps in functionality of the tool suite and provide a research road map for tool improvements. To meet these objectives, there are five different elements to the assessment program: parametric sensitivity and uncertainty analysis; comparisons to gold standard data (a benchmark that is regarded as the most reliable, representative, or complete information available); expert reviews; capability demonstrations and sample problems; and the system-level assessment. The uncertainty analysis uses total sensitivity indices to rank the inputs by cause of output uncertainty.

FUTURE VISION

Future environmentally responsible aviation policy and rulemaking needs to be based on a new, interdisciplinary approach. This approach should be made as affordable as it is effective and informative. Integrated modeling tools are needed to effectively assess and communicate environmental effects, trade-offs, interrelationships, and economic consequences. Accordingly, FAA, in collaboration with NASA and Transport Canada, is three years into a multiyear effort to develop a robust new comprehensive framework of aviation environmental analytical tools and methodologies that will enable more informed federal policy and budgetary decision making and facilitate international agreements on standards, recommendation practices, and mitigation options. The long-term aim is to provide a seamless, comprehensive set of tools to address all aspects of aircraft noise and emissions.

When completed, the new EDS-AEDT-APMT tool suite will allow government agencies to understand how proposed regulatory actions and policy decisions impact aviation noise and emissions; industry to understand how technology, design, and operational decisions related to proposed airport and airspace projects affect aviation noise and emissions; and the public to understand how actions by government and industry impact community noise and emissions. In coordination with the Next Generation Air Transportation System Joint Development and Policy Office, the tool suite currently is being used for environmental-related scenarios and policy analyses.

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 the following:

- For EDS, combine existing NASA acoustics and performance modules with engine emissions models into an integrated package for evaluating interrelationships between noise and air pollutant emissions at the aircraft level, taking into account aircraft cost considerations, performance capabilities, and operational factors. We must create the software architecture, design module links, and harmonize database architecture such that a seamless interaction between the tools exists under different technology and policy scenarios.
- For APMT, integrate research advances for new environmental impact metrics, econometrics modules, and socio-economic data.
- For AEDT and APMT, advances are needed to fully integrate the various elements of each model, as well as create a user interface and input and output protocols.
- Advance the quantitative assessment of the tool suite at the system level and continue uncertainty analysis to provide guidance on the level of confidence that we can place on tool outputs and encourage international acceptance.

FAA is pursuing development of EDS, AEDT, and APMT with their intended uses ranging from design and technology impact studies, to airport improvement projects, to noise and emissions certification standards rulemaking.

REFERENCES

Connor, T., and L. Q. Maurice, 2005. Aviation's Impact on the Environment: Addressing Interrelationships, *Journal of Aviation Management*, pp. 67–77.
www.trb.org/conferences/aedt-apmt/.
www.faa.gov/about/office_org/headquarters_offices/aep/models.

Technology Deployment

Richard L. Altman
Commercial Aviation Alternative Fuels Initiative

Research into the fundamental effects of aviation on the environment of the type described in the previous sections of this paper cannot be converted into improvements that would reduce those effects unless the recommended technologies are actually developed and deployed in the field. The pace and scope of deploying new technologies within the aviation enterprise in an increasingly complex future depends on numerous factors, many of which are not well understood. These factors include the following:

- **How to introduce new technologies within the existing aviation system interface constraints—**Demonstrating the efficacy of new technology to meet its intended environmental goal is necessary but not sufficient to ensure its deployment in aviation. New technology intended to address environmental performance must meet the same high reliability, durability, maintainability, and increasingly significant security standards applied to other components of the aircraft. These requirements can be a barrier to deployment by disqualifying some technologies entirely, mitigating the net environmental gain, or producing high economic penalties.
- **How to make new technologies marketable—**Manufacturers outside aviation or conglomerates may not perceive aviation to be a sufficiently large market or have a viable business model to support development of products tailored to this sector. For example, there is minimal fuel cell or micro turbine research concentrating on potential airport applications although it could be used in many pieces of airport equipment.
- **How to determine costs and benefits of new technologies—**The economic costs and benefits to end users of technology that has an environmental benefit to communities are not well understood, and there is no widely accepted metric by which to measure them.
- **How to develop optimal trade-offs—**The interrelationship of aircraft components may force sub-optimization of one technical characteristic to avoid sacrificing others. For example, innovations in engine technology resulted in quieter, more fuel-efficient aircraft but increased emissions of nitrogen oxides.
- **How to stimulate commercial risk-taking—**Government research programs in the United States are not developing new technology to a level that would allow private enterprise to adopt it at reasonable risk. In the past, the National Aeronautics and Space Administration (NASA) sponsored technology to the system demonstration level known as Technology Readiness Level 6 (TRL6). For example, during the 1980s, NASA sponsored both engine and aircraft full-scale demonstrations under its aircraft energy efficiency program that were taken to TRL6, which produced significant innovation in commercial products in the ensuing years. No such programs exist today.

- **How to meet future demands—**At the same time that technology innovation has flagged, the national needs for dramatic improvements in reducing aviation's impacts on the environment have become more obvious. The Next Generation Air Transportation System (NextGen) currently is being defined by the Joint Planning and Development Office (JPDO) to enable up to a threefold capacity increase in air traffic. The JPDO is incorporating an environmental plan to ensure that there is no growth in environmental exposure in the United States as this capacity growth occurs, but such a plan depends on deployment of advanced technology.
- **How to address future issues—**Emerging issues, particularly those that are not governed by aviation-specific regulatory bodies at the time of their emergence—such as particulate matter, hazardous air pollutants, and deicing—require thorough aviation-specific research before optimum solutions can be identified, and often even longer time periods before appropriate technologies can be designed, produced, and introduced into the market. Without such definition well in advance of control requirements being defined, timely development and deployment of solutions is not possible.

CURRENT STATE

Aviation faces the challenges of a maturing industry. The pace of innovation has decreased as the aviation industry has matured. Technological advances over the past 50 years have resulted in aircraft and engines that are increasingly quieter, are more fuel efficient, and produce fewer pollutants. During the last decades of the 20th century, new commercial aviation systems were deployed at a rapid pace, filling voids in aircraft size and range and frequently following on the heels of military aircraft developments in similar size and speed classes. At this time, the feasible range of speed and size for commercial aircraft has been explored and few voids exist. Most of the current technological innovation takes the form of improvements to existing aircraft types, and the economic barrier to replacing an existing product in the same size and speed class is high.

Some research is beginning to be conducted that addresses critical deployment issues. For example, the issue of optimal technology trade-offs in aircraft design was first evaluated by a consortium of airline operators and manufacturers in support of international regulatory investigations earlier this decade. It is being addressed further under the Federal Aviation Administration's (FAA) Environmental Design Space initiative. It is anticipated that the shortfall in environmental capacity resulting from the planned threefold increase in aviation activity will be identified by the JPDO evaluation and analysis division.

FUTURE VISION

Additional data, analysis, and tools to improve deployment of environmental technologies are needed to address the collective goals of all participants. That data and analysis should cover the full spectrum of issues affecting deployment, be usable by all interests, and enable informed decision making by creating the best possible understanding among and between the engaged enterprise components. Means of communicating this information are needed as effectively as possible across the aviation enterprise and to those that interface with it. We envision that the generation of this information will in turn lead to a reduction in the barriers to technology deployment and thus allow reductions in the impact of aviation on the environment.

RESEARCH NEEDS

Specific research needs identified to best address the critical issues in technology deployment are the following:

- Conduct research on business processes to include identification and investigation of case studies from other transportation modes and similar technology-intensive industries. Determine how technology innovation has best occurred in other industries that depend on environmental performance and are in similar mature positions on the S-curve of industry life cycle. Such management science studies can produce lessons that are applicable to aviation as it migrates through its maturity phase.
- Develop an adequate benchmark of case studies of specific technologies that had to meet equally high standards as they have progressed from demonstration to implementation and insertion at a systems level. Such a set of studies can alert evaluators to the scope and magnitude of penalties that can be anticipated in the deployment of new aviation environmental technologies.
- Target research and review case studies to identify the transferability of environmental technologies first deployed in other industries to aviation. This in turn would establish aviation feasibility for systems shown to be reliable and safe and could enable users to create strategies that cross multiple markets. Conversely, while aviation may not be the largest market for some technologies, it may have characteristics (contained–controlled test space) that make it desirable for beta (user insertion) testing of new products targeted for multiple markets. Offers by the aviation industry to house such tests could speed insertion into the general market. Research should be targeted to identify opportunities where this approach may be attractive.
- Research is needed to determine the costs and benefits of environmental improvements. While the acquisition and recurring cost consequences of new technologies are available to operators from manufacturers, the research need is for third party (neither seller nor buyer) monetization of benefits to operators if existing economic penalties are ameliorated through improved product performance. Here, amelioration can take the form of reduced fees, capacity constraints, purchase of environmental credits, and operational changes such as noise abatement flight tracks. For Department of Defense (DoD) operations, amelioration may take the form of reducing tanker requirements, training costs, or maintenance costs if the most effective basing cites are unavailable. This research recommendation follows the initiative to develop a balance sheet of costs and benefits, which was an outcome of the Aviation Environmental Portfolio Management Tool workshop conducted by the Transportation Research Board at the request of FAA during the first quarter of 2005.
- Continue research to determine optimal trades among environmental factors in aircraft design at least into the production flight test phase where product form, fit, and function are established.
- Research ways to reduce the risk of introducing new technology and stimulating commercial investment. For example, quantify, in an objective manner, the percent chance of success and payoffs for key technologies and systems of multiple technologies. The DoD–NASA technology readiness process, which has existed since the 1990s, can be used as a model to collect data on projects at all risk levels.
- Research that quantifies the benefits and costs of developing and deploying advanced technology to meet NextGen capacity requirements to the satisfaction of all enterprise

components needs to be executed in a timely manner. By identifying enterprise pull (motivated by potential growth), this research could define a basis for market-based deployment based upon national objectives.

- Research means of establishing mechanisms to detect at the earliest possible occasion new environmental requirements that could impact aviation.
- Identify and evaluate where government action (other than research) has accelerated identification and deployment of technology in aviation and in other industries both inside and outside the United States. Careful selection of these examples to ensure that they have similar key characteristics as aviation will be critical to this initiative's success. Better understanding of how such tools can be used most effectively would enable the U.S. government to speed deployment of aviation technologies that would benefit the environment.

REFERENCE

Environmental Integrated Product Team, 2005. *Technology Pathways—Assessing the Integrated Plan for Next Generation Air Transportation System*. International book number 0-309-65283-PDF, Appendix G, Draft Plan.

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. Ralph J. Cicerone 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. Charles M. Vest 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. Ralph J. Cicerone and Dr. Charles M. Vest are chair and vice chair, respectively, of the National Research Council.

The **Transportation Research Board** is one of six major divisions of the National Research Council. The mission of the Transportation Research Board is to provide leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal. The Board's varied activities annually engage about 7,000 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. **www.TRB.org**

www.national-academies.org

TRB
TRANSPORTATION RESEARCH BOARD
500 Fifth Street, NW
Washington, DC 20001