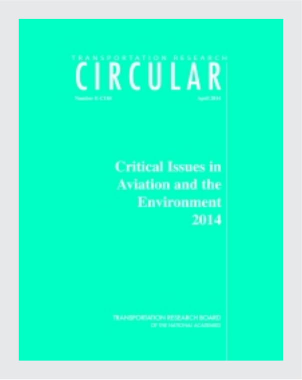
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Critical Issues in Aviation and the Environment 2014

Prepared by the
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Introduction

A focus on the environment and sustainability plays an increasing role in the development and operation of aircraft and airports. As a result, the aviation industry is investing significant resources to understand and minimize the environmental impacts of aviation. Nevertheless, environmental issues have become a fundamental constraint to increasing aviation system capacity. Moreover, constrained capacity can further exacerbate certain environmental problems, such as noise and impacts on local air quality.

Some environmental impacts are well understood but significant research will be required to understand other existing and future impacts as well as the opportunities for mitigation or avoidance. To illustrate, an appropriate response to climate change requires an improved science-based understanding of the climate impacts of aviation emissions. In addition, improved metrics, measurement techniques, and modeling capabilities are needed to quantify and predict impacts and their consequences and to understand interrelationships of aviation-related environmental issues. This e-circular summarizes progress being made on certain environmental issues and suggests additional research to help achieve that vision.

The TRB Environmental Impacts of Aviation Committee focuses on environmental issues central to airport planning, design, construction, and operation, as well as related aviation system and aviation technology development. The committee issued its first report on Critical Issues in Aviation and the Environment in the United States in 2004, followed by revised editions in 2005, 2009, and 2011. This 2014 revision updates and expands upon the previous circulars, maintaining a cross-disciplinary approach to reviewing subjects of interest to the civil aviation community. This report also groups the papers into three general categories: the environmental impacts of aviation; sustainable solutions to addressing those challenges; and processes and tools for implementing sustainable solutions.

Critical Issues in Aviation and the Environment 2014 consists of 12 individually authored sections, representing the authoring experts' opinions on issues that address the major environmental components affected by aviation activities, sustainable solutions that have evolved and continue to be developed to minimize environmental impacts, and the key processes that link aviation and the environment. As in past versions, the focus of this e-circular is on the state of science, rather than policy, and on identification of priority research with potential to yield benefits during the next several years to several decades.

This e-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 additional resources at the end of each section. Due to scope constraints, the critical issues portions of each section do not necessarily address all potentially critical issues in a given field.

The individually authored papers represent the viewpoints of the attributed authors. Members and friends of the Environmental Impacts of Aviation Committee have also reviewed and contributed comments to these papers. Appreciation is expressed to the authors and reviewers of these papers.

—Mary Ellen Eagan
Harris Miller Miller and Hanson Inc.
Environmental Impacts of Aviation Committee, Chair

1

Environmental Impacts of Aviation on Human and Natural Resources

1 ENVIRONMENTAL IMPACTS OF AVIATION ON HUMAN AND NATURAL RESOURCES

1.1

Noise

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1.1.1 INTRODUCTION

Aircraft noise has historically been, and continues to be, a major constraint on airspace use and expansion of civil aviation capacity, despite aircraft technology improvements and a significant reduction in the number of people exposed to high aircraft noise levels (Figure 1). Noise continues to be a constraint on aviation growth. Communities continue to be annoyed about aircraft noise and concerned about the effects of aviation noise, including sleep disturbance and speech interference. Both the federal government and the aviation industry are actively working to mitigate the effects of aviation noise on communities. Noise research plays a major role in both aircraft technology development and an improved understanding of the effects of noise on people. This paper focuses on critical issues in civil aviation noise related to impacts on people, including a discussion of recent trends and emerging issues, ongoing research, and research required to assist with environmental decision making.

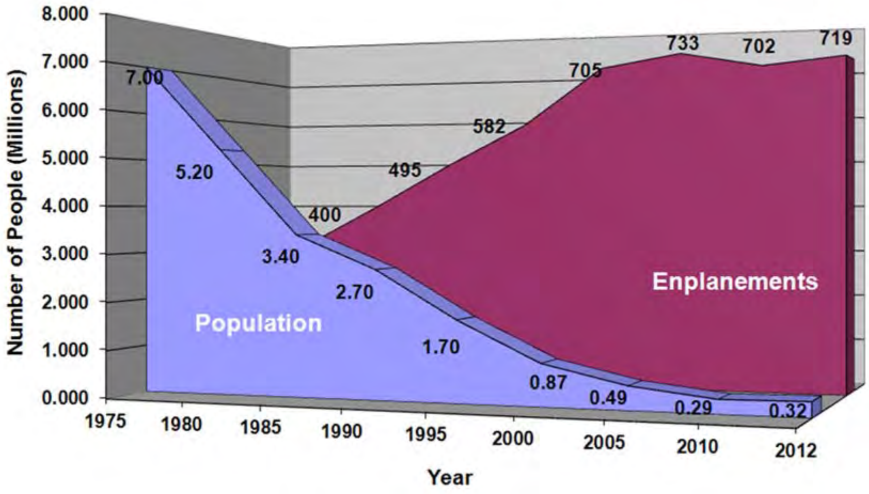

FIGURE 1 The historical record: order of magnitude of noise exposure reduction despite traffic growth.[1]

1.1.2 CURRENT STATE

The state of practice for aviation noise assessment has been constant for over 30 years, based on the noise and land use compatibility guideline of day–night average sound level (DNL) of 65 dB. U.S. federal agencies coordinate research priorities and findings through the Federal Interagency Committee on Aviation Noise (FICAN), which was formed to provide a forum for debate over future research needs to better understand, predict, and control the effects of aviation noise and to encourage new technical development efforts in these areas. Currently its members include the U.S. Department of Transportation, the U.S. Department of Defense (DOD), the Environmental Protection Agency (EPA), the National Aeronautics and Space Administration (NASA), the U.S. Department of Housing and Urban Development, and the U.S. Department of the Interior.

The technical basis for noise policies was last reviewed by FICAN in 1992,[2] which identified a value of DNL 65 dB as the threshold of land use compatibility. This threshold was first identified by researchers in 1970s and corresponds to about 13% of the population that will report high annoyance. For FAA environmental reviews under the National Environmental Policy Act of 1969, DNL increases of 1.5 dB to levels of 65 dB or more are considered significant noise impacts. The noise policy is based on a correlation between transportation noise exposure level and the percent of the population highly annoyed by it. This work was published by Schultz 30 years ago and included all modes of transportation (air, rail, and road).

Currently, human health impacts of aircraft noise are captured primarily by a sleep awakening standard, based on the correlation between noise level and self-reported awakening.[3] Recently more accurate measures have been developed by medical professionals to assess sleep deficiency by physiological techniques, but physiological findings are not currently linked with aviation noise policies. One of the important challenges of this work is defining appropriate metrics that can be used for environmental policy-making decisions.

Significant progress has been made in recent decades regarding aircraft noise abatement, at the source as well as in flight, and investment in mitigation has been strong:

- **Technology.** Significant advances in aircraft and engine design technology have resulted in much quieter aircraft. In February 2013, the International Civil Aviation Organization (ICAO) reached a consensus on a new noise standard.[4] The agreed noise standard will be 7 effective perceived noise level below ICAO’s current standard and will be applicable to new aircraft types certified after 2017 for takeoff weights greater than 75,000 lb and after 2020 for the lower weight aircraft.
- **Abatement.** The FAA is implementing the Next Generation Air Transportation System (NextGen), a major modernization of the National Airspace System (NAS).[5] Performance-based navigation (PBN) capabilities enable more direct routes and provide alternatives for routing around NAS disruptions, such as bad weather or unexpected congestion. PBN procedures may help reduce fuel use, miles flown, and emissions, as well as the number of people exposed to noise while aircraft transition during the arrival or departure phase of flight. Typical applications of PBN include optimized profile descent (OPD) and tailored arrival operational procedures, which may provide fuel, emissions, and noise benefits.
- **Mitigation.** The FAA and U.S. airports have invested billions of dollars in residential and school sound insulation programs to bring interior noise to acceptable levels.

The scientific and technical base for noise policies is constantly updated. For example, the FAA and its partners are funding various programs for advancement of aviation noise research including the Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER) and the Airport Cooperative Research Program (ACRP).

1.1.3 FUTURE VISION

As noted, the FAA is currently implementing NextGen, making several operational improvements to the NAS.[6] In order to sustain the developments of NextGen, community noise concerns must not pose a significant growth constraint.[7, 8]

NextGen has raised many environmental issues specifically related to noise, including new aircraft technologies.

- **Aircraft technology.** In partnership with industry, the FAA initiated the Continuous Low Energy, Emission, and Noise (CLEEN) program.[9] The noise objective is to cumulatively reduce aircraft noise from aircraft engines and airframes to 32 dB below the ICAO Chapter 4 (U.S. Stage 4) standard.[10] One of the new directions is development of methodologies to model noise propagation for current and potential future unconventional aircraft configurations, including the increasingly attractive open rotor concept. This concept was rejected in the 1980s due to the high level of open rotor noise but has since been revisited, having demonstrated potential for significant fuel reduction. New experimental data is required to support open rotor noise model development and validation, and evaluation of efficiency of the existing noise metrics.[11] Analysis conducted to date has demonstrated increased low frequency spectra content.[12]
- **Unmanned aircraft systems (UAS).** UAS are currently authorized for limited use in the NAS, but are being further integrated by the FAA, as directed by the 2012 FAA Reauthorization legislation.[13] Similarly, NASA is working to reduce technical barriers related to the safety and operational challenges associated with enabling routine UAS civil access to the NAS.[14] At present, the majority of UAS are operated by military and law enforcement agencies. However, while growth forecasts vary, increased use of UAS in the NAS is generally expected to continue for law enforcement, border security, commercial, agricultural, traffic monitoring, disaster relief, and other purposes. For this purpose, the FAA established the UAS Integration Office in 2012, tasked with integrating UAS into the NAS for public use.[15] The size, type, and propulsion of UAS vary widely as technology is evolving quickly, ranging from models with wingspans as large as a Boeing 747 or smaller than a radio-controlled model airplane.[16] UAS propulsion also varies widely, ranging from turbojet to electric driven propeller. The FAA forecasts that the largest near-term growth will be for small UAS.[17] UAS have varied flight operation trajectories and operating altitudes, ranging from just above ground level to above 65,000 ft.[18] Given these variations, noise characteristics will need to be defined for those aircraft within their respective operating environments, many of which extend beyond those of typical aircraft. A regulatory framework for UAS does not yet exist, although the FAA is making a significant effort toward that need. ACRP has a pending Project 03-30: Unmanned Aircraft Systems at Airports: A Primer, which is proposed to consider factors including the environment and compatible land use.[19]
- **Supersonic flight.** As demand for long-range business travel increases and technologies for efficient supersonic flight mature, a market for small supersonic civil aircraft

appears to be forming. However, a major remaining impediment to the operation of such aircraft is sonic boom.[20] NASA, FAA, and industry partners are studying technology that will reduce the noise and annoyance associated with sonic booms in an effort to facilitate the allowance of supersonic flight over populated areas. One of the primary efforts revolves around "shaping" of the sonic boom waveform through airframe design in order to reduce loudness and potential annoyance. NASA is exploring the feasibility, benefits, and technical risk of vehicle concepts and exploring enabling technologies that will reduce the impact of aviation on the environment. Scale models are tested in supersonic wind tunnels. In addition, NASA contract studies are underway to design a scaled supersonic X-plane demonstrator to replicate the noise signatures produced by a full-scale aircraft. Additional research is underway to better understand human response to sonic booms.[21] Examples of past and ongoing research by NASA include the Waveforms and Sonic boom Perception and Response project. The primary purpose of developing the study was the development of developing data collection methods for future public perception studies. In addition, NASA is involved with two other programs, the Superboom Caustic Analysis and Measurement Program with measurements designed to validate computer prediction tools, and the Farfield Investigation of No Boom Threshold, which is studying evanescent waves, an acoustic phenomenon that occurs at the very edges or just outside of the normal sonic boom envelope. Research continues to be focused toward both reducing noise at the source and understanding the effects of sonic booms.[22]

- **Commercial space.** Research and development is conducted to support an emerging industry of commercial space transportation. The FAA Office of Commercial Space Transportation and the Commercial Space Transportation Advisory Committee forecast the total demand of 291 commercial launches for the 10-year period between 2012 and 2021.[23] FAA's launch regulations require a license or a permit for all commercial launches taking place within U.S. borders, as well as for launches being conducted abroad by U.S. entities. Launch noise assessment is becoming more of an issue because of the introduction of new launch sites and commercialization of space travel, and the requirement for accurate acoustical tools. To predict far-field launch vehicle noise, acoustic models have initially been based on the distributed source method reported by NASA SP-8072.[24] The majority of recently designed system prediction validations are conducted using experimental scale models[25], but it is unclear how these finding can be translated to full-scale vehicles. Sonic boom impact computations are required for some new launch sites to ensure that flights entering or leaving the United States will not cause a sonic boom. The existing sonic boom models are used to predict maximum noise level on a certain distance.[26] However, FAA noise evaluations are based on DNL, and loud and infrequent supersonic noise events do not necessarily translate well with the DNL metric.
- **Helicopters.** Throughout the United States, helicopter utility has expanded for a wide variety of work applications (e.g., law enforcement, medical response, news gathering, real estate viewing, site seeing, commuter travel, power line service) and the numbers of flight operations have increased appreciably, from which more noise is perceived by the general public. Depending on the time of day, geographic location, and human activity setting, the noise emitted by rotorcraft is causing public annoyance and triggering noise complaints. Helicopter noise is currently evaluated with the same land uses compatibility guidelines used for other fixed-wing aircraft. However, the frequency content, altitudes and operational procedures of these vehicle types are different. Current acoustical theories do not describe helicopter annoyance on the same scale of perceived sensitivity with that of fixed wing airplanes. Better capabilities are needed to characterize, model, and quantify human response to helicopter noise.

1.1.4 RESEARCH NEEDS

A comprehensive Aviation Noise Research Roadmap[27] was formulated for the U.S. agencies interested in and affected by aircraft noise in 2011. The target of this research is to provide a firm scientific basis for evaluating and updating U.S. noise policy. The roadmap document described to the extent possible all noise impacts research and issues of multiple federal agencies on the following research areas: noise effects on health and welfare, aircraft noise modeling, noise in national parks and wilderness, and costs of aircraft noise on society. Scientific work targeting some of the research gaps identified in the Roadmap document is currently underway.

- **Annoyance.** Currently available evidence shows that aircraft noise is perceived as more annoying than noise from other modes of transportation. Since the last annoyance data was collected in the United States, not only has operations changed such that the quieter, more frequent operations are occurring, but there is also evidence that communities' tolerance for aviation noise has decreased. New social surveys data is needed to update the scientific evidence of the relationship between aircraft noise exposure and its effects on community. An active ACRP project, Research Methods for Understanding Aircraft Noise Annoyance and Sleep Disturbance,[28] is aimed at development and validation of the research protocol for a large-scale study of aircraft noise exposure–annoyance response relationship across the United States. This protocol will be utilized in a follow-up national survey study, which was initiated by the FAA at the end of 2012. This extensive data acquisition campaign has the following objectives: (*a*) data collection to gain a better understanding on how aviation noise is perceived by communities around airports and (*b*) creation of a new dose–response curve based on updated data collected by a national survey in a scientific, systematic way to represent the wide breadth of airports in the United States. During this project, residents around a wide variety of U.S. airport types and geographic location will be surveyed. Approximately 20 civilian airport surroundings will be surveyed using the same methodology.
- **Health.** There is a need to understand the relationship between aviation, noise, and health outcomes. Studying this relationship in the United States is a challenge that needs a nationwide health database with high-resolution data. Since impacts do not result in health problems immediately, a longitudinal, multiyear medical cohort is needed. A cost-effective option of conducting such a study is to use preexisting medical data sets.[29] Therefore, several initial attempts have been made to investigate applicability of existing medical cohorts including a pioneering attempt to investigate the relationship between airport noise and existing self-reported insufficient sleep for the entire United States was conducted jointly by the Centers of Disease Control and Prevention and FAA. The research methodology developed during this work serves as a basis for a continued study of noise health impacts. Another attempt included looking at health risks associated with noise in the vicinity of each airport by employing national data on Medicare enrollees and noise contours for the same airports as in the earlier study.[30] Here noise metrics are linked with zip code-level data on air pollution exposure, population demographics, socioeconomic factors, and other individual-level and zip code-level covariates.
- **Sleep.** Aircraft noise disturbs sleep, interferes with residents' rest, and may contribute to long-term health consequences. The last U.S. study on effects of aircraft noise on sleep was performed in 1996. Up-to-date exposure response relationship data is critically needed to assess the validity of current nighttime noise policy and better mitigate effects of aircraft noise on sleep. The research was tasked to

  - Develop an optimal study design for the U.S. field study;
  - Develop modes that can predict changes in total sleep structures bases on traffic volume and patterns, and
  - Generate awakening maps for airports.
- **Health.** The research protocol for the initial U.S. field study of sleep disturbance due to airport noise has been developed within the PARTNER project, Noise Exposure Response: Sleep Disturbance.[31] The proposed combination of actigraphy (watch-shaped sensors that measure accelerations of body movements) and electrocardiography would allow a cost-effective and methodologically less-invasive sound investigation of large subject cohorts. The developed protocol will be implemented and validated within a pilot study near one U.S. airport in the near future. Exposure–response relationship between noise characteristics of single aircraft event and physiological reaction (e.g., awakening) will be the primary outcome of field studies.
- **Effects of noise on children's learning.** Children's learning is an emerging area of potential noise impacts investigation. There is evidence that chronic exposure to noise is associated with learning deficits in children. The effectiveness of sound insulation for schools is analyzed using the student test scores as a metric.[32] However, this research does not examine the effects of aircraft noise on student and teacher interaction. Classroom observations are needed to determine at what level noise events cause interruptions and how student and teacher communication and behavior is affected by aircraft noise. In addition to noise at school, noise exposure leading to interrupted sleep at night potentially can affect children's health and cognitive development.

In summary, further research is needed for the following purposes: (*a*) to assess whether a correlation exists between aircraft noise and health effects; (*b*) to quantify potential noise impact on sleep and health; and (*c*) to define the levels of exposure at which health effects begin to occur. Laboratory psychophysical experiments could deduce the basic information on dose–response effects on brain, cardiovascular, and other systems and relevant outcomes. They could also establish relevance of age and sex to response, and brain dynamic as a predictor of response. However, natural environment experiments would demonstrate better causality, ability to make repeated measures of exposure and effects, disease progression, and disease–environment interactions. The longitudinal (e.g., prospective) experiments would potentially demonstrate the most reliable results. Another challenge lies in the differentiation between effects of different exposures. Continued study of health should also include behavioral noise effects, particularly on vulnerable populations (e.g., children). Beyond funding issues, the interdisciplinary nature of this research poses a unique challenge, because physiological and engineering expertise is simultaneously required.

1.1.5 CASE STUDY

TRB's *ACRP Web-Only Document 9: Enhanced Modeling of Aircraft Taxiway Noise, Volume 2: Aircraft Taxi Noise Database and Development Process* documents the procedures developed and employed in the creation of a taxi noise database for the FAA's Integrated Noise Model and Aviation Environmental Design Tool (AEDT). The AEDT is currently under development. It is available at http://www.trb.org/main/blurbs/168805.aspx.

1.1.6 ADDITIONAL RESOURCES

ACRP Project 03-30: Unmanned Aircraft Systems (UAS) at Airports: A Primer. Available at http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3443.

FAA Aerospace Forecasts for Fiscal Years 2013–2033. Available at http://www.faa.gov/about/office_org/headquarters_offices/apl/aviation_forecasts/aerospace_forecasts/2013-2033/media/2013_Forecast.pdf.

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Partnership for Air Transportation Noise and Emissions Reduction (PARTNER) Project 8: Sonic Boom Mitigation. Available at http://web.mit.edu/aeroastro/partner/projects/project8.html.

U.S. Department of Defense press release regarding unveiling of the Global Hawk Unmanned Aerial Vehicle. Available at http://www.defense.gov/releases/release.aspx?releaseid=1165.

NOTES

1. Noise exposure data comes from the FAA's annual noise inventory, published in the annual FAA Performance and Accountability Report. The report is available at http://www.faa.gov/about/plans_reports/media/fy2012par.pdf. The enplanement data is from the FAA 2012 Terminal Area Forecast. The data is available at http://www.faa.gov/about/office_org/headquarters_offices/apl/aviation_forecasts/taf_reports/ media/taf_summary_report_fy2012.pdf).
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1.2

Air Quality

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1.2.1 INTRODUCTION

Over the past two decades, air pollution associated with aviation and airport-related sources has become a prominent issue facing commercial and general aviation airports in the United States. According to the General Accountability Office, aviation emissions are estimated to account for less than 1% of concentrations of the criteria pollutants carbon monoxide (CO), nitrogen dioxide (NO_2), ozone, and its precursors, oxides of nitrogen (NO_x) and volatile organic compounds, sulfur dioxide (SO^2), and particulate matter (PM_{10} and $PM_{2.5}$) over the United States.[1] Aircraft are one of the few mobile sources with relatively high allowable fuel sulfur content since the introduction of ultra-low sulfur fuel in diesel motor vehicles and nonroad equipment. In addition, lead (Pb) emissions are an issue for general aviation since more than 167,000 piston engine aircraft rely on leaded aviation gasoline for safe operation and produce about half of all Pb emissions in the United States.[2] Nevertheless, aviation sources, like those associated with other transport modes, can contribute to air quality degradation issues and that contribution may grow. Although aviation-related emissions are quite small nationally, these emissions are not uniformly distributed, and boundary mixing layer emissions are concentrated at airports. Worldwide aviation traffic, as measured by available seat-miles, is expected to increase at an average rate of approximately 2.9% per year between 2013 and 2033.[3] Increased aviation demand and activities will likely lead to an increase in aviation emissions if these emissions cannot be mitigated.

At present, about 30% of the busiest U.S. airports are located in nonattainment and maintenance areas for National Ambient Air Quality Standards (NAAQS), as established by the EPA.[4] This percentage is expected to increase as the EPA continues to adopt increasingly stringent air quality standards, a frequent trend over the past 7 years. For example, in 2006, the EPA lowered the 24-h $PM_{2.5}$ standard from 65 micrograms per cubic meter (ug/m^3) to 35 ug/m^3, with 122 counties designated to be in nonattainment with the new standard.[5] EPA revised the 8-h ozone standard from an effective value of 84 parts per billion (ppb) down to 75 ppb for both primary and secondary standards in 2008.[6] This change potentially increased the number of counties in ozone nonattainment from 85 to more than 300.

Also in 2008, EPA lowered the existing lead standard 10-fold to 0.15 ug/m^3 for a 3-month rolling average, which focused much attention on general aviation activity since aviation gasoline contains the additive tetraethyl lead.[7] Initial EPA lead monitoring studies indicate that a subset of airports exceed the lead standard in close proximity to takeoff areas.[8] As a result, a number of general aviation airports have become the focus of public concern due to potential exposure to lead concentrations associated with piston engine aircraft operations. Jet fuel for commercial jet and turboprop aircraft does not contain lead additives and does not emit lead.

In 2010, EPA finalized the new 1-h NO_2 primary standard at 100 ppb and expanded the NO_2 monitoring network, particularly by creating a monitor network intended to measure NO_2 peaks at roadways.[9] Increased attention to short-term peak concentrations of NO_2 may lead to increased pressure to characterize peak NO_2 concentrations in airport vicinities. Also in 2010, EPA finalized the new 1-h SO_2 primary standard at 75 ppb.[10] Finally, in 2013 EPA lowered the annual $PM_{2.5}$ primary standard from 15.0 to 12.0 ug/m^3.[11]

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 pollutants both at the surface and at altitude along the flight path. Aircraft emit the bulk of the emissions (approximately 90%) above 3,000-ft altitude. Traditionally, assessments of surface air quality analyze aircraft emissions within the landing and takeoff (LTO) cycle between the surface and 3,000 ft. Aircraft emissions within the LTO cycle are addressed by the emission standards established by the International Civil Aviation Organization (ICAO) for aircraft engines, and adopted by the United States, which are made more stringent as technology advances. Aircraft combustion turbine engine emissions of several pollutants (CO, NO_x, hydrocarbons, and smoke) are measured during new engine certification tests to demonstrate compliance with the ICAO and U.S. standards. However, the U.S. ambient air quality standards for $PM_{2.5}$ were developed long after the old engine smoke standard was adopted by ICAO, so the method to collect engine PM emissions (i.e., smoke number) does not currently support any studies or evaluations of aviation impacts on ambient $PM_{2.5}$ concentrations.

There are currently no known ways to determine strictly from monitoring networks whether pollutants measured in the atmosphere are due to aviation or other sources, increasing the difficulty of determining how much of air quality degradation is due to aviation. Current scientific knowledge indicates that, once emitted, aviation pollutants evolve and transform in a similar way to those from other emission sources and are indistinguishable from those present in the background air. Research on several approaches to aircraft and aviation source contributions to air quality impacts continues to examine several apportionment techniques. This is discussed in more detail in the next section below.

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 their ultimate fate via atmospheric transport and transformation into 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 (GHG) and climate change, alternative aviation fuels, and modeling tools are addressed in other sections of this e-circular.

1.2.2 CURRENT STATE

The United States launched a long-term plan for the NextGen. NextGen involves an integrated effort to ensure that the future air transportation system meets air transportation security, mobility, and capacity needs while reducing environmental impacts. Implementation of NextGen addresses strategies to reduce aviation's impacts on air quality in absolute terms as it identifies research and development needs that will enable advanced modeling capabilities for predicting such impacts, as well as interrelationships with noise and climate impacts. Current research and development activity needs and schedules are summarized in the NextGen Integrated Work Plan FY 13[12] and the NextGen Implementation Plan.[13]

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, has been carried out by the FAA–NASA–Transport Canada–DOD–EPA sponsored Center of Excellence: PARTNER and ACRP, which is managed by TRB.

Over the past decade, research on the air quality impacts of aviation has focused on several key issues:

1. Quantifying and characterizing criteria and HAP direct emissions from large commercial in-use aircraft engines and auxiliary power units when operating on conventional or alternative aviation fuels,
2. Measuring ambient air quality in the vicinity of airports and attempting to estimate the contribution of airport operations to those measured levels,
3. Understanding aircraft exhaust plume chemistry and transport from cruise altitude to ground level, and
4. Identifying potential approaches to mitigating aviation-related impacts on air quality.

1.2.2.1 Quantification and Characterization of Aviation-Related Emissions

- Under the ongoing emissions quantification research, substantial work has been focused on developing a method to measure nonvolatile PM from turbine aircraft engines to replace ICAO's First Order Approximation Methodology, Version 3 (FOA3), currently used to estimate PM emissions from the smoke number. The Society of Automotive Engineers (SAE) Aircraft Exhaust Emissions Measurement committee has recently developed the Aerospace Information Report (AIR) 6241, Procedure for the Continuous Sampling and Measurement of Non-Volatile Particle Emissions from Aircraft Turbine Engines. AIR 6241 defines the standard methodology to be employed to extract and measure PM number and mass-based emissions from the exhaust flow of aircraft engines. The quantification of PM number and mass-based emissions will provide a robust means to assess impacts on local air quality and health effects, going beyond the visible obscuration (smoke number) measurement method of Aerospace Recommended Practice (ARP) 1179 and ICAO's FOA3.0a PM emissions modeling method. A demonstration of two prototype AIR 6241–compliant systems has been successfully conducted in Zurich, Switzerland, in November 2012, with very good agreement recorded between two compliant systems. Additional testing between compliant systems at engine manufacturer facilities is underway.[14]

- The SAE A21 Committee develops aviation-related noise and emissions modeling guidance via the publication of AIRs and ARPs. In 2009, the committee published AIR 5715, providing comprehensive guidance on various methods used to predict aircraft emissions, including the Boeing Fuel Flow Method 2 (BFFM2) which was also published as a standalone SAE technical paper. BFFM2 takes into account atmospheric conditions and engine bleed effects, and is regarded as the current state-of-the-art open methodology used to predict aircraft emissions superseding the ICAO reference method that simply multiplied the ICAO emissions indices with times in mode values. Currently employed in the FAA's Emissions and Dispersion Modeling System, BFFM2 is also slated to be included in AEDT to allow calculation of NO_x, CO, and total hydrocarbon (THC) emissions. In addition to the methodologies, SAE AIR 5715 also provides guidance on understanding the uncertainties associated with each method.
- The emissions quantification and characterization research on commercial in-use aircraft turbine engines conducted under the Aircraft Particle Emissions Experiment (APEX) campaigns[15–18] between 2004 and 2008 has continued with the Alternative Aviation Fuel Experiment (AAFEX)[19–22] and related studies. The APEX series of experiments indicated that the gaseous pollutant emission indices measurements for wing-mounted in-use engines match reasonably well with the certification test results contained in the ICAO engine emissions databank. However, the AAFEX measurements on the same engine used for testing in the APEX-1 study indicated that engine performance and emissions degrade over time. The AAFEX study included measurements of both aircraft engine and auxiliary power unit (APU) emissions using conventional and alternative aviation fuels. Several other key findings from these experiments indicate:
  - The emission indices of CO and THC are much higher at 4% thrust setting, commonly used during idle and taxi, than the 7% taxi–idle setting assumption for the ICAO certification tests. Taxi–idle emission inventories of CO and THC may be underestimated when using the ICAO idle emission rates.
  - PM emissions are primarily in the ultrafine particle (UFP) size range, with mean diameters ranging from 15 nm at idle to 35 nm at takeoff.
  - PM number emissions increased with increased fuel sulfur content and increased fuel aromatic content. PM from secondary formation (volatile PM) can provide a very high contribution to measurements made at 30 m and further distances from the engine exit plane.[23, 24]
  - THC, volatile PM, and nonvolatile PM emissions decrease with increasing ambient temperature.
  - The speciated hydrocarbon profile (relative composition of each compound in the exhaust gas THC mixture) for a given fuel and engine is relatively constant across all thrust settings. This finding allowed for the development of a common THC speciation profile for commercial turbine aircraft for all thrust settings fueled on Jet A.[25, 26]
  - Relative to conventional fuels, burning pure alternative [Fischer-Tropsch (FT) and hydroprocessed esters and fatty acid (HEFA)] fuels generally reduced engine CO, THC, and NO_x emissions. Blended fuels did not provide much reduction.
  - Burning the FT fuels, either pure or blended with conventional fuels, resulted in substantially reduced engine PM emissions.
  - GHG emissions [CO_2, methane (CH_4), and N_2O] were not significantly influenced by fuel composition. However, measurements of ambient CH_4 and engine exhaust CH_4 indicate that aircraft destroy more CH_4 than they produce over a typical flight profile.

1.2.2.2 Ambient Air Quality in the Vicinity of Airports

Several recent studies have focused on measuring ambient air quality in the vicinity of an airport and attempting to correlate airport activity with the temporal and spatial variations in the measurements or with source or receptor modeling.[27–34] In addition, the recently published *ACRP Report 71: Guidance for Quantifying the Contribution of Airport Emissions to Local Air Quality*[35], provides guidance for quantifying airport emission contributions to local air quality. Several key findings from these studies include:

- The relative contribution of airport activity to local air quality is highly dependent on wind direction, distance between airport and receptor (monitor), season, and pollutant. While these findings are intuitive, they present challenges when attempting to estimate an airport's contribution to local air quality.
- Airport activity shows:
  - Little correlation with PM_{10} and $PM_{2.5}$ concentrations,
  - Some temporal correlations with CO for near-field downwind monitors,
  - Potential correlation with NO_x, carbonyls (formaldehyde and acetaldehyde), and black carbon (BC) at downwind locations, and
  - Direct correlation with SO_2 and UFP concentrations for local monitors.
- It should be noted that NO_x and BC concentrations may include contributions from nonaircraft airport sources, such as cargo and passenger motor vehicles as well as ground support equipment (GSE). To advance efforts to understand the role of BC, in 2009 Congress requested the EPA to conduct a BC study. The results are presented in the March 2012 Report to Congress on Black Carbon.[36] While UFP concentrations can be associated with aircraft activity, the current understanding of UFP impacts on human health is not sufficient to develop a health-based ambient standard or threshold.[37]
- In studies that included atmospheric chemical transformation modeling, such as Community Multiscale Air Quality (CMAQ), secondary formation of $PM_{2.5}$ and ozone included contributions of precursors emitted by airport sources. Even with this capability, airport activity was not highly correlated with these secondary pollutants.
- Receptor modeling techniques that rely on chemical compositions of measurements, such as the chemical mass balance (CMB version 8.2) receptor model supported by EPA[38] can make determinations regarding source types, such as diesel exhaust versus gasoline exhaust versus jet engine exhaust. However, these chemical modeling methods cannot distinguish between diesel engines on equipment and vehicles associated with airport activity and those nonairport engines operating in the local area.
- The nonparametric trajectory analysis (NTA) that relies on minute averaged measurements of concentrations and meteorology can provide estimates of source locations and, once a source location is defined, NTA can provide a rough estimate of source contribution of a given pollutant to a given monitoring station.
- Sampling certain pollutants, such as speciated organics, will require long sampling periods to collect enough samples to be above system detection limits. This reduces the ability to get high time resolution necessary for the NTA analysis. Therefore, spatial gradient sampling with many passive (low or no power required) samplers over weeks or months provides another approach to potentially identify sources.

- Measurements of criteria pollutants near airports generally indicate that ambient concentrations in the airport vicinity are no worse than those measured elsewhere in the urban or suburban region in which the airport is located. In PARTNER Project 33, Isotopic Analysis of Air Quality, recently completed in June 2011, the analyses were developed to aid in high precision determinations of community exposure attributable to aircraft and other airport sources, a critical question for interpreting local community concerns and for designing future campaigns; however, the results were not conclusive in indicating that this technique could be used for this purpose.[39]

1.2.2.3 High Altitude Emission Impacts on Ground Level Air Quality

The effect of aircraft emissions at cruise altitude on potential impacts on ground-level air quality is highly uncertain. These impacts have traditionally been considered negligible due to the limited vertical mixing through the temperature inversion layer (i.e., mixing height). However, several recent scientific studies suggested that non-LTO aircraft emissions also contribute to degradation of surface air quality.[40–42] These studies implicate secondary aerosol formation from NO_x and SO_x emissions at altitude as the major source of the effects on surface-level health. One study noted the transportation process alone takes too long for most pollutants to reach the surface without undergoing substantial physical–chemical transformation or physical removal by wet deposition.[43] One of the studies also notes aviation impacts on human health in the United States is noticeably less than any other transportation mode (automobile–truck, rail, shipping).[44]

1.2.2.4 Potential Approaches to Mitigating Aviation Impacts on Air Quality

Several approaches are currently being studied to reduce aviation-related impacts on air quality. The examples noted below focus on in-flight aircraft operations, nonaircraft sources at airports, and fuels. The approaches listed below can reduce emissions of criteria air pollutants, HAPs, and GHGs.

- In the operations area, OPD has proven to be a highly advantageous maneuver over conventional arrival and approach procedures that require combinations of level flight segments and descents. From the environmental perspective, it has resulted in significant reductions in emissions due to reductions in thrust.
- A PARTNER project, En Route Traffic Optimization to Reduce Environmental Impact, demonstrated en-route airspace throughput (the number of aircraft that can safely fly though a given location over a given time) can be increased by optimizing aircraft cruise altitude and speed based on the distance between their origin and destination. The increase in throughput, and the corresponding reductions in fuel burn and emissions, results when aircraft can fly closer to the optimum altitude for their performance characteristics.[45]
- Another aspect of flight operations studied was the reduced vertical separation minima (RVSM). RVSM is the standard vertical separation required between aircraft flying at certain specified levels. It reportedly enhances aircraft operating efficiency. The environmental benefits of RVSM were examined and the conclusion was an estimate that RVSM led to an improvement of fuel burn of 1.8% ± 0.5%.
- As part of NASA's Aeronautics Research Mission Directorate Fundamental Aeronautics program, emissions characteristics of new technology aircraft engines have been

studied while emissions impacts of large-scale NAS studies have been conducted under the airspace systems program. Such studies illustrate the assessment of NextGen-related technologies and future scenarios, including those involving the implementation of ICAO's Committee on Aviation Environmental Protection (CAEP) combustor emissions reduction goals. For example, the environmentally responsible aircraft (ERA) project under the Integrated Systems Research Program demonstrated the potential for inserting a new twin-aisle aircraft design meeting the emission reduction goal on a NAS-wide basis.[46]

- NASA is also conducting a project under the NextGen Concepts and Technology Development program involving a study of local air quality improvements due to the optimization of airport surface (taxi) movements. This marks one of the few instances where NASA is directly studying air quality impacts rather than just quantifying emissions only.
- Aircraft APU use at airports represents an emissions source for which existing alternative systems are available. *ACRP Report 64: Handbook for Evaluating Emissions and Costs of APUs and Alternative Systems*[47] provides a handbook for evaluating emissions and costs of APUs and alternative systems that may be used to reduce APU use.
- The first step in gaining a better understanding of airport GSE impacts on emissions was conducted and summarized in *ACRP Report 78: Airport Ground Support Equipment Emission Reduction Strategies, Inventory, and Tutorial*[48],which includes a national GSE inventory and discussion of potential emission mitigation options for GSE.
- The formulation of alternative aviation fuels noted above is one possible approach that shows some promise.[49–51]

1.2.3 FUTURE VISION

Through its ERA project, NASA is currently developing demonstrations that address five additional areas of potential mitigation techniques: aircraft drag reduction, weight reduction, advanced engine fuel use reduction, engine combustor emission reductions, and airframe and engine integration designs to reduce fuel use.[52]

In addition, FAA's CLEEN program is in the process of demonstrating new technologies, procedures, and sustainable alternative jet fuels that are intended to reduce the negative impact of aviation on air quality, noise, and the climate. Five-year agreements were awarded to five companies to develop and demonstrate a variety of impact-reducing pathways by 2015.[53]

FAA and its partners, under the Commercial Aviation Alternative Fuels Initiative (CAAFI), will continue their efforts to develop, approve, and deploy alternative aviation fuels that have positive impacts on aircraft emissions and air quality through reductions in PM and SO_2, and life-cycle CO_2 emissions. Activities under NextGen include the exploration and qualification of additional classes of sustainable aviation alternative fuel blends that use novel feedstock's and conversion processes. Approval of fuel blends exceeding 50% alternative fuels will extend these air quality benefits by further reducing PM, SO_2, and life-cycle CO_2 emissions. Also related to alternative fuels, FAA has established a goal to identify a replacement, unleaded aviation gasoline for piston-engine aircraft by the year 2018.[54]

1.2.4 RESEARCH NEEDS

1.2.4.1 Quantification and Characterization of Aviation-Related Emissions

- **Fuels:**

  – Alternative aviation fuels for turbine aircraft need to continue to be assessed for potential reductions in emissions of criteria air pollutants, HAPs, and GHGs. Initial studies on FT and HEFA synthetic fuels, as well as on ultra-low sulfur petroleum fuels shows promise in reducing PM emissions.

  – Because aviation gasoline is the only mobile source fuel with a Pb additive, research is needed to support the development of an unleaded avgas fuel to replace the 100LL currently used. As noted above, the FAA plans to identify a suitable replacement to 100LL by 2018.
- **Engine exhaust plume characteristics:**

  – Current modeling of aircraft exhaust plumes uses a static plume height based on LIDAR plume studies. However, the hot exhaust gas is likely to rise buoyantly for some time before cooling sufficiently to continue dispersion with further rise. The impacts on local air quality modeling where peak concentrations are reported are generally conservative (see the Los Angeles Airport Source Apportionment Study as described in Section 1.2.6[55]). Research is needed to develop a distance-based or time-based aircraft engine exhaust plume rise algorithm for use in regulatory dispersion models.

  – Previous studies of low-power (taxi–idle) engine emissions indicate these emissions may be underestimated using current modeling methodology. Identification of an appropriate engine thrust setting for current taxi and idle conditions commonly used by pilots should be developed, and emissions associated with this setting should be incorporated into AEDT.

  – Since the adoption of the 1-h NO_2 NAAQS, it is becoming important to understand the NO_2–NO_x ratio in aircraft engine exhaust plumes and the rate at which NO is converted to NO_2 downwind of the aircraft. As alternative aviation fuels are tested, the NO_x plume chemistry should be monitored at the engine exhaust plane and at one or more downwind locations.

  – Research is needed to support completion of an ARP for measuring and certifying aircraft engine PM emissions, and incorporate measured PM emissions (g/kg fuel) into the ICAO aircraft engine emissions databank.
- **Other airport-related sources:**

  – Develop updated emission factors for nonaircraft emission sources at airports such as GSE and motor vehicles. Particular attention should be focused on developing factors for Tier 3 and Tier 4 diesel engines as well as alternative fueled (propane and natural gas) engines in the fleet.

  – Continue to develop emission estimates and emission factors for aircraft landing emissions associated with brake and tire wear.

1.2.4.2 Ambient Air Quality and Health Effects in the Vicinity of Airports

- The nonparametric trajectory analysis (NTA) method for locating sources and quantifying source contribution has shown some promise for airport air quality analysis.[1] Use of the method should be studied to further identify its strengths and weaknesses in the context of source apportionment for airports in urban environments.

- Health effects of UFP derived from aircraft turbine engines should be assessed in comparison to those from UFP derived from diesel engines. Measurements indicate that aircraft-related UFP are smaller than diesel-related UFP; however, it is not clear whether the aircraft-related UFP are more, less, or the same as diesel UFP with regard to health impacts. Since these pollutants are usually comingled in the environment, the studies would probably need to be controlled in clinic trials and animal tests.
- Research demonstrates that PM dominates human health risk.[16] However, the extent to which the health effects and risks are associated with different particle sizes is not clear. As an extension to the previous recommendation, health effects associated with several different sizes should be assessed. Size categories such as 0.5 to 1 micron, 0.1 to 0.5 micron, 0.05 to 0.1 micron and less than 0.05 micron could be assessed to address the range from turbine-engine UFP through diesel-engine UFP and BC, and on to other primary and secondary particulates.

1.2.4.3 High-Altitude Emission Impacts on Ground-Level Air Quality

- Health impacts of high-altitude emissions include
  - Continue modeling and measurement research to reduce the uncertainty in estimated ground level pollutant concentrations associated with emissions aloft.
  - Conduct research to determine if $PM_{2.5}$ is the appropriate form of PM for assessing aircraft-related health impacts.

1.2.5 CASE STUDY

1.2.5.1 LAX Air Quality and Source Apportionment Study

The air quality monitoring conducted during Phase III of the Los Angeles International Airport (LAX) Air Quality and Source Apportionment Study consisted of two 6-week field measurement campaigns: winter monitoring season from January 31 to March 13, 2012, and summer monitoring season from July 18 to August 28, 2012. Three types of monitoring sites (four core, four satellite, and nine gradient), with different combinations of continuous monitors and time-integrated (24-h and 7-day) samples, were used to determine how the ambient concentrations of various chemical species of interest varies by location, time of day, day of the week, and season.

More than 400 individual compounds and pollutants were measured including criteria pollutants, regulated pollutants, compounds that have been designated as toxic air contaminants by the California Air Resources Board or hazardous air pollutants by EPA, and other chemical species that are useful for source characterization and apportionment, including UFP and BC.

The airport contributions to ambient air quality were estimated by the CMB and NTA receptor models, and the American Meteorological Society–EPA Regulatory Model, a Gaussian dispersion model, and the CMAQ grid-based air-quality simulation model.

The ambient concentrations of CO, NO_2, SO_2, and Pb within the communities adjacent to LAX were well below the threshold levels for exceedance of the national and state health-based ambient air quality standards during the study period. $PM_{2.5}$ levels were near the ambient air quality standard; however, the CMB estimates of source contributions to ambient $PM_{2.5}$ mass were

1% to 2% and background-adjusted (i.e., airport-related) vehicle exhaust contributions to ambient $PM_{2.5}$ is estimated to be 4% to 9%.

The contribution of airport-related emissions can vary by hour of the day, day of the week, and by season. Factors such as airport activity levels, wind direction, wind speed, ambient temperature, and other meteorological parameters affect the contribution of airport-related emissions to local ambient air quality.

Figure 1 presents an example of results obtained from the NTA analysis for the Community East (CE) site and Community North (CN) site during the winter monitoring season. These sites are downwind of the prevailing wind direction from the airport. The BC daily profile is similar to NO_2 and CO profiles in that the airport's contribution is lowest when the ambient concentrations are highest indicating contributions from other regional sources are the major contributors during the peak ambient concentration periods. On the other hand SO_2 and UFP contributions are noticeably driven by on-airport sources, primarily aircraft. The complete, final report is available at http:// www.lawa.org/welcome_LAX.aspx?id=2554.

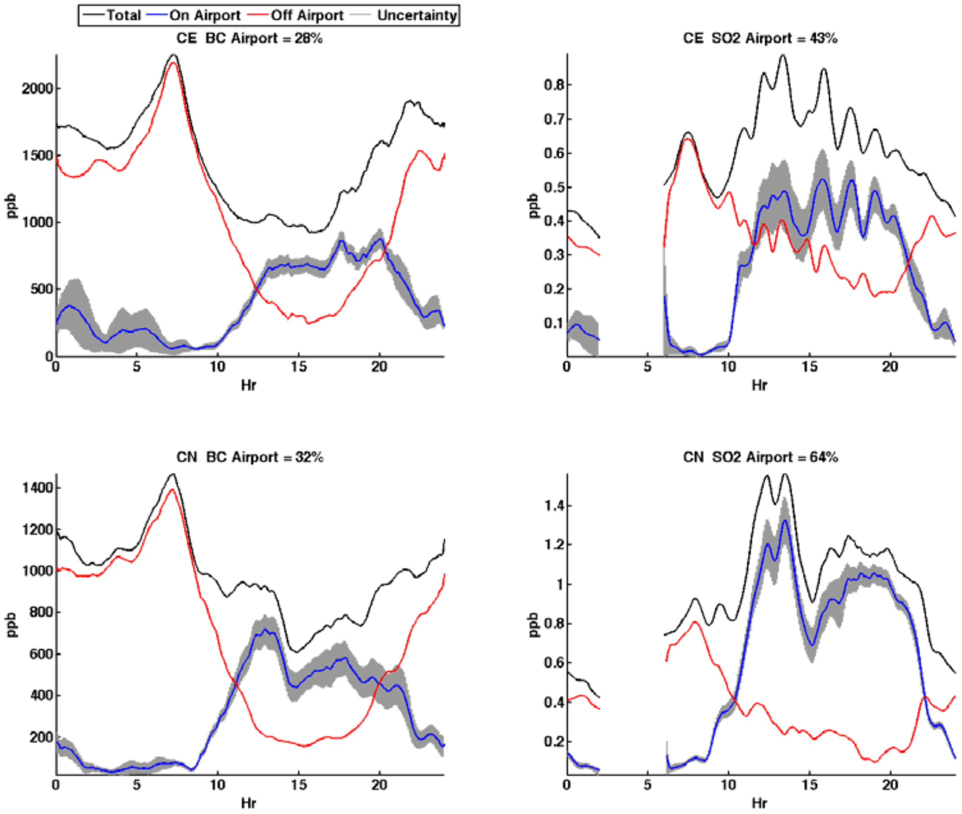

FIGURE 1 Winter monitoring season NTA source apportionment of BC and SO_2, and UFP for CE and CN sites. The black lines are the total contribution, red are the off-airport contribution (from both nonairport- and airport-related sources), and blue is the on-airport contribution. The on-airport contribution line contains the upper and lower limits (gray shaded), which include the estimated effects of random error and assumptions made in the computations.[56]

NOTES

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1 ENVIRONMENTAL IMPACTS OF AVIATION ON HUMAN AND NATURAL RESOURCES

1.3

Climate Change

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1.3.1 INTRODUCTION

It is the general consensus within the scientific community that the observed global warming and attendant climate change is being driven by the anthropogenic increase in the combustion of fossil fuels and other activities that generate GHGs. The primary GHG, aside from water vapor, is CO_2, with CH_4 being the next most important gas. CO_2 now accounts for approximately 77% of global anthropogenic GHG emissions, with CH_4 second at 14%.[1]

Combined air temperatures over land and ocean, from 1880 to the present, show an increase in the temperature anomaly from the background (1901–2000 average), with all years in the 21st century showing an anomaly between 0.5°C and 0.6°C above background.[2] Figure 1 shows the trends in atmospheric CO_2 concentrations and global average surface temperature from 1880–2009.[3] Current values for atmospheric CO_2 recently reached 400 ppm in May 2013.[4]

Transportation accounts for 26% of global energy use and 23% of all anthropogenic GHG emissions (estimated for 2004).[6] Aviation's contribution to CO_2 emissions from fuel burn is relatively well understood and estimated to be approximately 2% of the annual global total. However, CO_2 is not the only combustion product from aircraft; other important emissions include NO_x, SO_x, PM (including BC), and water vapor, which forms contrails and induced cirrus clouds. An additional component unique to aviation is that most of its emissions are produced at cruise altitude which is a sensitive region for atmospheric processes. The total impact of aviation on global radiative forcing, is estimated to be between 3.5% and 4.9% of total anthropogenic forcing[7], including the 2% from aviation-generated CO_2. These effects, as well as new research coming from the FAA-sponsored Aviation Climate Change Research Initiative (ACCRI)[8] are the focus of ongoing and future research. This is described in the following sections on the current state of research and practice. Understanding these impacts is critical, as ICAO anticipates aviation fuel use to grow from 200 million metric tons in 2006 to approximately 700 to 900 million metric tons by 2050, depending on advances in operational efficiency and airframe–engine technological developments.[9]

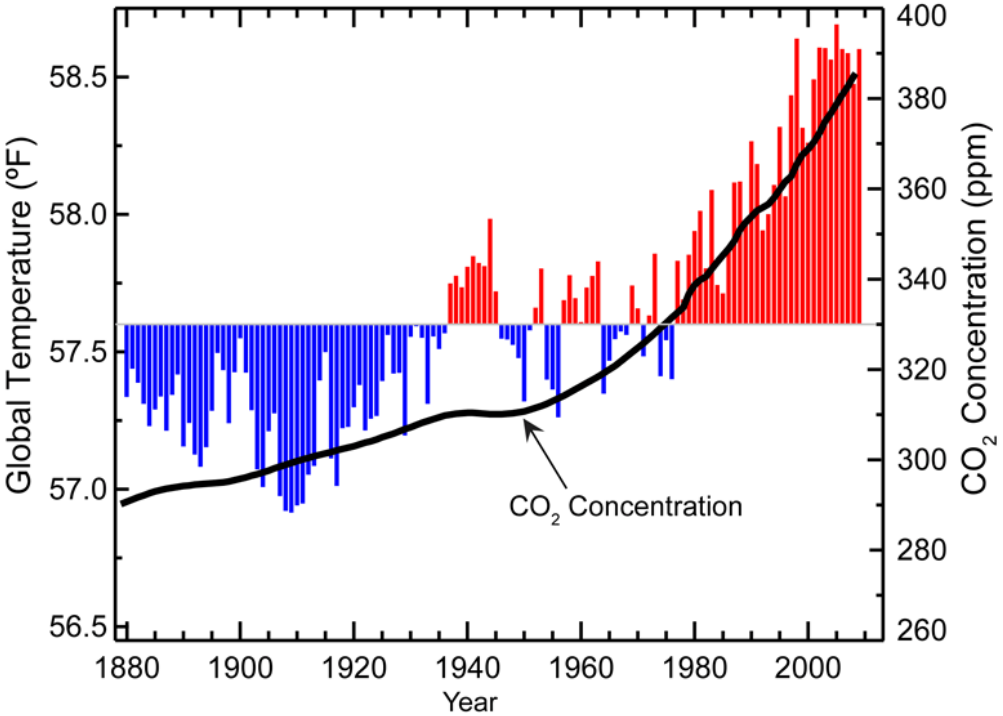

FIGURE 1 Trends in atmospheric CO_2 concentrations and global average surface temperature, 1880–2009.[5]

1.3.2 CURRENT STATE

1.3.2.1 Aviation Effects on Climate: Current State of Research

Aircraft combustion produces both CO_2 and non-CO_2 emissions that contribute to climate change.[10, 11] Aviation CO_2 emissions are indistinguishable from those of any other source and the impact of these emissions on climate change is well known. Climate impacts of aircraft non-CO_2 emissions (i.e., NO_x, SO_x, and PM) and those due to contrail and induced cirrus clouds are quite heterogeneous in space and time and are also quite uncertain. For example, the Intergovernmental Panel on Climate Change's (IPCC's) climate change 2007 report on the physical science basis listed low to very low level of scientific understanding for climate forcing due to contrails and induced cirrus clouds respectively.[12] That has led to the recent focus of the science community on characterizing the magnitudes of aviation non-CO_2 impacts with associated uncertainties not only for the present conditions but also for the future.[13, 14]

Earlier aircraft climate impacts assessment studies have developed estimates of global climate forcing in terms of radiative forcing (RF) while modeling the evolution of aircraft emissions in chemistry–transport models. The IPCC[15] defined RF as the change in net (down minus up) irradiance (solar plus longwave; in W m–2) at the tropopause after allowing for stratospheric temperatures to readjust to radiative equilibrium, but with surface and tropospheric temperatures and state held fixed at the unperturbed values. Despite articulated limitations[16], RF is widely used as a metric to express aviation contributions to climate impacts.

There are atmospheric feedbacks and interactions that have the potential to modify aviation non-CO_2 climate impacts. Therefore, there is an increasing focus to include them in climate research studies and was, in fact, part of the principal basis of the creation of the FAA-sponsored ACCRI[17] that has just completed its Phase II activities. ACCRI also focused on defining and analyzing options for metrics for aviation climate impacts. Figure 2 depicts the aviation climate analysis framework that ACCRI adopted. An ACCRI consortium, comprised of 10 teams of international researchers was formed to perform research involving model simulations, laboratory measurements, and analysis of observational data to develop a comprehensive portrait of aviation contribution to climate change. ACCRI researchers employed a range of chemistry–climate models of varying complexities as well as detailed individual flight-based chorded and gridded global emissions inventories. (Note that aviation climate impact studies include only global aircraft emissions from gate to gate activities). Ongoing FAA research is assessing ACCRI results for regional fingerprints of aviation-induced climate change to develop a methodology for estimating changes in surface temperature that can be used in simple climate models widely used in the cost–benefit analyses to support decision making (e.g., the Aviation Portfolio Management Tool[18]).

Figure 3 provides ACCRI estimates of certain components of aviation impacts that were previously reported by Lee et al. (2009).[19] (Note that aircraft CO_2 emissions contribute nearly37% of the total RF when RF for induced cirrus clouds is included). In general, ACCRI RF estimates are comparable to those reported by Lee et al (2009), as referenced above. However, large ranges of RF from aviation NO_x emissions still exist. This is due to several factors, including how well different models simulated the background atmospheric chemical composition, as well as details of chemistry and transport schemes represented in chemistry–climate models. Several research groups within ACCRI studied contrails and induced cirrus clouds. An important outcome of ACCRI and other related work elsewhere, has led to an

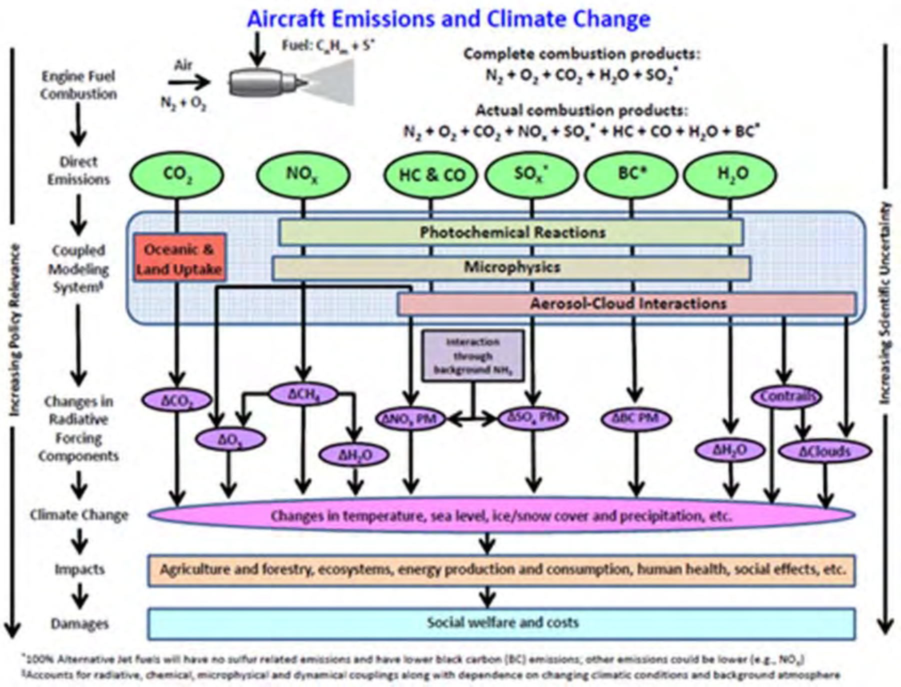

FIGURE 2 A schematic flow linking aircraft emissions to their contributions to climate change.[20]

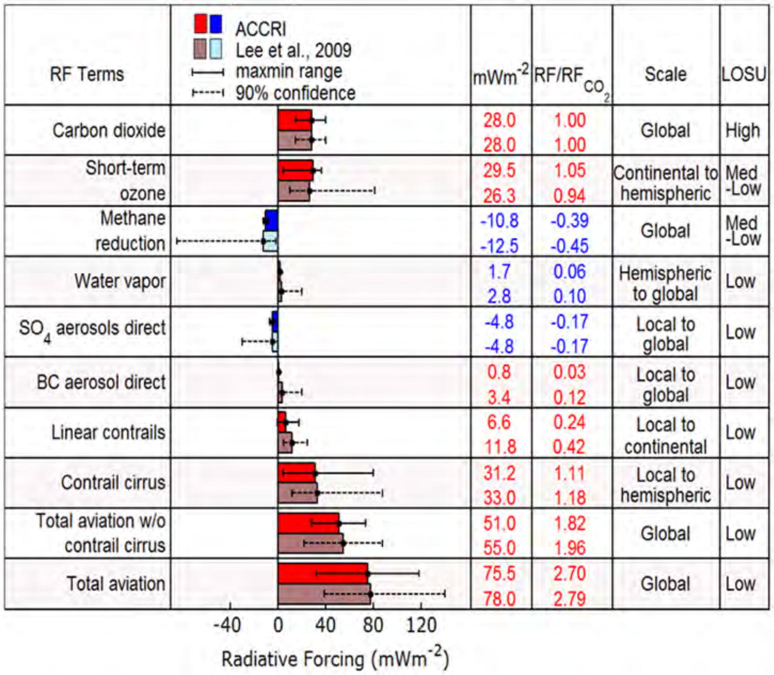

FIGURE 3 ACCRI results comprising global RF components, spatial extent, and level of scientific uncertainty are shown here for the various components for 2006. The total RF in the last two rows is a sum of all individual radiative forces without and with contrail cirrus RF, respectively. Note that contrail cirrus RF also includes linear contrail RF, which has been subtracted from total aviation RF to avoid double counting. Red bars correspond to warming agents, blue bars correspond to cooling agents, and whiskers correspond to the minimum and maximum range of RF for each effect. The values of the minima and maxima are summed to provide the minimum and maximum, respectively, in the total values.[21]

upgrading of the level of scientific understanding for induced cirrus clouds from very low to low. ACCRI research has characterized new components of aviation RF including long-term changes in ozone (cooling), stratospheric water vapor, and nitrate aerosols (cooling). Part of the ACCRI research team has simulated net reduction in cirrus clouds cover, thus resulting in a net negative RF, due to aviation aerosol-induced sedimentation of water vapor and localized warming. Qualitatively, this result is similar to that reported by Burkhardt and Karcher (2011)[22] but is highly uncertain and underlying mechanisms still need to be well understood.

The ACCRI consortium also focused on future climate impacts for 2050 for baseline and mitigation-based aircraft emissions scenarios that included a 2% per year increase in fleetwide fuel efficiency due to combined advances in aircraft technologies and environmentally efficient operational procedures as well as introduction of 50% blended renewable drop-in alternative jet fuels. Combustion of renewable fuels is inherently low in BC emissions and also void of sulfur emissions. Initial ACCRI results show that introduction of renewable biofuels will offset to some extent net non-CO_2 climate impacts due to projected growth in aviation activities.

ACCRI results show there are key interactions and mechanisms, such as the aerosol–cloud interactions superimposed with background characteristics (chemical, dynamical, microphysical, and thermal) of the cruise altitude region that need to be further evaluated to constrain underlying uncertainties. This is particularly important when future aircraft emissions with blended renewable alternative fuels will be introduced in the atmosphere with different background chemical and aerosol composition as well as thermal balance. Recent studies also indicate that evolution of a chemically reactive plume perturbs the chemical composition differently from the approach where aggregated and gridded emissions are used. More research is needed to develop a simplified parametric methodology to simulate individual flights based chemical evolution of plumes on a global scale and to evaluate the net impact on aviation-induced RF.

1.3.2.2 Aviation Effects on Climate: Current State of Practice

Reduction in fuel burn implicitly leads to net reduction in aircraft combustion emissions that contribute to climate change. There are many technological (both aircraft and fuels), gate-to-gate operational procedures and airspace management avenues that are being concurrently pursued to reduce fuel consumption and emissions. In addition, internationally accepted emissions standards and market-based measures are other avenues to limit aircraft emissions.

Traditionally, advances in airframe and aircraft engine technologies have contributed to most of the fuel burn savings that the aviation system enjoys today. Through programs such as CLEEN (funded by the FAA), ERA (funded by NASA), the Advisory Council for Aeronautics Research in Europe, and the Green Aviation Research & Development Network in Canada, there are coordinated government–industry partnership efforts to develop mature aircraft technology for fuel and emissions reduction to a higher level of readiness for quick penetration into the operating fleet. Some of the CLEEN and ERA technologies will also help reduction exclusively in NO emissions that, as discussed before, contribute to climate change.

As stated before, introduction of drop-in renewable alternative jet fuels, which are devoid of sulfur emissions during combustion, could not only reduce CO_2 emissions during the entire life-cycle process but would also reduce emissions of nonvolatile BC (nvPM), and possibly emissions of gaseous NO_x. In addition to reducing direct RF, decreases in direct emissions of PM and those of gaseous precursors will also limit the potential for contrail formation. Through coordinated aviation community efforts under initiatives such as CAAFI, significant advances have been made on multiple fronts including environmental sustainability analyses, flight demonstrations, and efforts to identify and employ fuel production pathways. In fact, ASTM International has already approved the use of renewable synthetic HEFA fuel blended as a 50% mixture with conventional jet fuel. In addition, a jet flight test with 100% biofuel has already been demonstrated.

Next generation air traffic and airspace management programs such as NextGen[23] and the European Union (EU) Single European Sky Air Traffic Management Research[24] are paving the way for not only transforming the efficiency, safety, and mobility of the aviation system, but are also providing environmental protection through satellite and digital technology-driven direct and precise aircraft routing. Advances in gate-to-gate (surface and en-route) operational procedures through initiatives such as the Atlantic Interoperability Initiative to Reduce Emissions[25] and the Asia and Pacific Initiative to Reduce Emissions[26] have clearly demonstrated significant environmental and fuel burn benefits.

1.3.2.3 Aviation Effects on Climate: Current State of Policy

Policy measures, such as goals to achieve carbon neutral growth and fuel efficiency as well as internationally accepted environmental standards, can contribute to emissions reduction. This section briefly reviews extant legislation regarding CO_2 emissions from aviation and means of reducing climate impacts of other aviation emissions (e.g., NO_x, PM).

The first attempt at a global limitation of CO_2 emissions was the 1997 Kyoto Protocol of the United Nations Framework Convention on Climate Change.[27] This committed signatories from developed nations and the EU to an average target of a 5% reduction from 1990 CO_2 emission levels by 2012. Neither aviation nor marine bunker fuels were governed by the protocol. The Doha Amendment, adopted on December 8, 2012, by the parties to the convention mandates a second commitment period for the Kyoto Protocol to January 1, 2020.[28]

For several years the ICAO Committee on Aviation Environmental Protection (CAEP) has been focused on developing an aircraft CO_2 emissions standard. CAEP agreed on a CO_2 metric system in July, 2012. It is anticipated that the proposed metric system will be approved by the ICAO council in 2013. The next step is the development of a regulatory level and its applicability. When an appropriate regulatory level and applicability for the CO_2 standard is agreed upon, it will go through formal review and approval.[29] CAEP has also recently approved more stringent NO_x combustion emissions requirements. Their work is continuing to employ standard nvPM emissions sampling and measurement methodology that will ultimately lead to defining and implementing the related standard. In addition, the international community agreed at the 37th ICAO Assembly to a global aspirational goal of 2% annual fuel efficiency improvements in the international aviation sector and stabilizing global CO_2 emissions at 2020 levels.[30] In contrast, the United States has set an ambitious overarching goal of achieving carbon-neutral growth for U.S. commercial aviation by 2020, using 2005 emissions as a baseline.

The U.S. Renewable Fuel Standard Program began with the Energy Policy Act of 2005, and was expanded under the Energy Independence and Security Act (EISA) of 2007.[31] Under this act, each renewable fuel must emit fewer GHGs than the petroleum it replaces. Some of the key components of the EISA pertain to transportation. With respect to aviation, the use of renewable drop-in alternative fuels offers the most effective way of reducing aviation's impact on climate and sustaining its projected growth. Renewable fuels not only provide an opportunity to lower greenhouse emissions over the entire life cycle but they also emit lower combustion gaseous and particulate emissions that contribute to climate change. The FAA has set a goal of annual use by U.S. aviation of 1 billion gallons of alternative jet fuel by 2018, thereby displacing 1 billion gallons of petroleum jet fuel.[32] Likewise, Flightpath 2050: Europe's Vision for Aviation calls for deployment of 2 million tons of sustainable biofuels by EU aviation by 2020.[33]

The EU adopted the Emission Trading System (ETS) in 2008 in an attempt to legislate CO_2 emission reductions.[34] Commencing in 2012, emissions from aviation were to be part of the EU ETS for all airlines. This meant that all airlines using EU airports were to pay for carbon emissions, including international intercontinental carriers. However, given international concerns over this legislation, the start date for this policy has now been postponed as of April 30, 2013, for 1 year to encourage agreement on an international aviation standard for CO_2 at the forthcoming 38th ICAO assembly.[35]

1.3.3 FUTURE VISION

Improved understanding of the non-CO_2 impacts of aviation will be essential in the future for addressing concerns related to aviation's contribution to climate change. Better quantitative estimates of aviation non-CO_2 effects such as NO_x, aerosols, contrails, and contrail-induced cirrus clouds, supported by models and observational findings, will further the development of technology and policy solutions for mitigating these impacts. Continued efforts toward improving aircraft technology and operations, developing internationally accepted policy measures, as well as adopting alternative aviation fuels on a large scale, will be critical toward mitigating aviation climate change impacts. Finally, carefully defined metrics that account for the disparate temporal, geospatial, and chemical properties of aviation's climate change impacts and quantification of associated uncertainties will be critical for measuring, valuing, and monitoring any progress toward reducing aviation's contribution to climate change.

1.3.4 RESEARCH NEEDS

- Follow-on work to better understand the key mechanisms, interactions, and feedbacks through which aircraft emissions interact with the ambient atmosphere under changing climatic conditions to reduce uncertainties in aviation NO_x, indirect aerosol, and contrail-induced cirrus effects.
- Assessment of future aviation-related climate change impacts using a range of growth scenarios incorporating improvements in airframe, engine, and fuel technology, as well as accounting for changes in atmospheric composition and ambient conditions that may influence aviation effects.
- Further investigation of aviation effects (long-term changes in ozone, stratospheric water vapor, and nitrate aerosols) identified in the ACCRI Phase II projects.
- Research on developing simplified parametric methods to simulate the chemical evolution of individual aircraft plumes on a global scale and assessing their net impact on aviation-induced RF.
- Development and refinement of global as well as regional climate change metrics for both CO_2 and non-CO_2 aviation impacts to support policy analysis needs.
- Refinement of current models that translate changes in RF from various aviation mechanisms to changes in surface temperature.
- Research on climate change impacts of supersonic aircraft emissions in the stratosphere.
- Research and analysis to further understanding of ecosystem and human health and welfare impacts of climate change effects to better inform aviation cost–benefit analysis. (Note this research would not be unique to aviation.)

1.3.5 CASE STUDY

1.3.5.1 Global Commercial Aviation Emissions Distributions

ACCRI simulated aviation effects on climate for the reference year 2006 using aircraft emissions computed by the AEDT. AEDT used the Common Operations Database of aircraft variant and engine information that includes about 31.3 million flights worldwide annually, burning 188 million metric tons of fuel. Flight activity data was constructed using three main sources of flight information, in order of increasing fidelity: International Official Airline Guide, Enhanced Tactical Flight Management System, and Enhanced Traffic Management System. For each flight, ACCRI computed fuel burn and emissions (CO, HC, NO_x, and PM by mass) on a chorded basis, and then processed the data into a 1° x 1° grid, each 500 ft in height. The global distribution of gridded aircraft emissions for year 2006 is shown in Figure 4.

AEDT also computed emissions for year 2050 for the baseline scenario that included generic modification in flight change due to growth and replacement in aircraft fleet. AEDT used aircraft projections for 2036 based on ICAO–FESG estimates and then extrapolations to the year 2050. Table 1 displays a comparison of fuel burn and NO_x emissions for years 2006 and 2050.

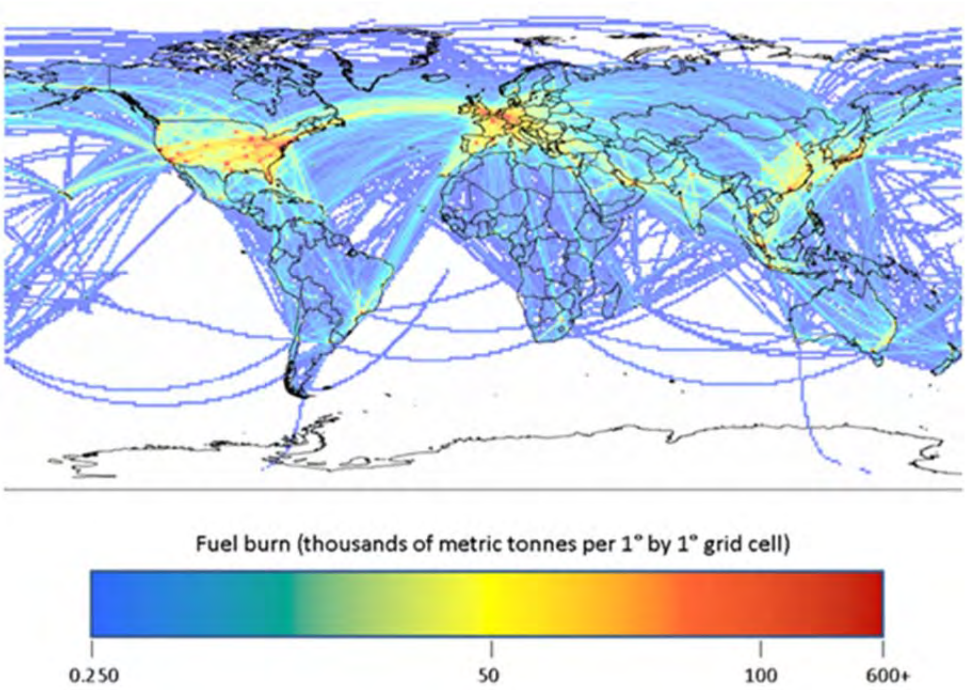

FIGURE 4 2006 total global aircraft fuel burn.[36]

TABLE 1 Summary of Actual (2006) and Projected (2050) Flights, Fuel Burn, and NO_x Emissions[37]

Analysis Year	Scenario	Flights	Fuel Burn (million metric tons)	NO_x (million metric tons)
2006	Actual	31,258,625	188.10	2.67
2050	Baseline	120,994,648	902.80	12.98

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35. http://ec.europa.eu/clima/policies/ets/index_en.htm.
36. http://unfccc.int/resource/docs/2013/smsn/un/127.pdf.
37. Courtesy of Gregg G. Fleming, U.S. Department of Transportation, John A. Volpe National Transportation Systems Center.

1 ENVIRONMENTAL IMPACTS OF AVIATION ON HUMAN AND NATURAL RESOURCES

1.4

Water Quality

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1.4.1 INTRODUCTION

Over the past two decades, interest and concern over the potential impacts of airport operations on water quality has increased. Environmental regulators are looking beyond the more obvious sources of water pollution (e.g., end-of-pipe industrial waste discharged into large water bodies) and are attempting to address issues such as attenuation of peak stormwater flows, erosion, and sedimentation and nonpoint source runoff. Airports, which typically include large areas of impervious surface 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 almost two decades, but the application of these rules to the unique operating environment of airports continues to be refined.

In recent years, new issues have emerged in the area of aircraft and airfield deicers and the environment. These include

- The EPA published Effluent Limitations Guidelines (ELG) and New Source Performance Standards for the Airport Deicing Category.[1]
- Several states have taken innovative approaches to National Pollutant Discharge Elimination System (NPDES) permitting of stormwater discharges associated with deicing activities.
- The aviation industry initiated a voluntary pollution reduction program aimed at reducing discharges of aircraft deicers on a national basis.
- Issues surrounding the compatibility of environmentally friendly airfield pavement deicers with aircraft and airfield infrastructure continue to be explored.

As well, regulatory requirements for stormwater from finished construction sites have created new challenges for stormwater managers. Similarly, emerging site-specific water quality considerations have developed concerning certain stormwater constituents and ecological impacts.

1.4.2 CURRENT STATE

1.4.2.1 Issues Surrounding Aircraft and Airfield Deicers and the Environment

Federal Regulation in the Posteffluent Limitation Guideline Era

On May 16, 2012, and effective June 15, 2012, EPA promulgated its final ELG.[2] While the ELG established effluent limitations related to the use of urea as a pavement deicer and for the discharge of aircraft deicing fluid runoff from new airports, EPA affirmatively decided not to establish effluent limitations for discharges associated with aircraft deicing at existing airports. Grounds for this determination included the agency's fundamental respect for the maintenance of flight safety in an industry already extensively and preeminently regulated by the FAA and its recognition that key model treatment technologies are not available to all airports as would be required by the federal Clean Water Act. Owing largely to the complexity of the variables that affect deicing runoff at existing airports, EPA left the development of technology-based permit limitations for existing airports to individual permit writers' exercise of their best professional judgment.

Innovative NPDES Permitting Approaches for Deicing Discharges

The potential for deicing chemicals in airport stormwater to negatively impact receiving waters began to be widely recognized in the late 1980s and early 1990s. During this period, regulatory agencies transitioned many airports with deicing operations from general NPDES industrial stormwater permits to individual NPDES permits. Some of the new individual permits included numeric limitations on discharge water quality. These limitations were often based on the best professional judgment of the permit writer or adapted from technology-based limits for other, typically very different discharge categories. Over time, airports with more stringent limitations found that they were unable to maintain consistent compliance, even with a well-run deicing runoff management program and no evidence of negative impacts on downstream water quality.

Recently, affected airports have sought to rectify the situation through negotiations with their regulatory agencies during permit renewal. An example of this trend is in Missouri, where Lambert–St. Louis and Kansas City international airports were issued individual NPDES permits in the 1990s that included discharge limitations based on municipal secondary wastewater treatment technology. In both cases, the airports implemented structural and nonstructural deicing runoff controls that significantly reduced the amounts of deicers in stormwater discharges, saw no evidence of downstream water quality impairments, and yet found themselves in periodic exceedence of their permit limitations. Working collaboratively with Missouri Department of Natural Resources during renewal of their NPDES permits, the airports and agency concluded that the current deicing runoff controls are operating as designed and there are no water quality impairments in receiving waters associated with airport stormwater discharges. With that foundation, statistically based water quality benchmarks were developed for each airport to reflect the performance of deicing runoff controls being operating as designed. These facility-specific benchmarks replace the numeric limitations in the previous permits. An observed discharge concentration above a benchmark triggers an investigation and appropriate corrective measures by the airport rather than a permit exceedence and potential enforcement action. Similar approaches are being explored and implemented in other states.

Industry-Led Voluntary Pollution Reduction Program

Four industry trade groups have announced the launch of their voluntary pollution reduction program. Airlines for America, Airports Council International–North America, the Regional Airline Association, and the American Association of Airport Executives will implement their voluntary program over the 5-year period from September 30, 2012, through September 30, 2017. During that period these partners will conduct outreach; encourage development, testing, and commercially appropriate deployment of pollution reduction technologies; develop an aggregate national pollution reduction goal; and produce a report comparing the environmental benefits of pollution reduction technologies adopted between 2005 and 2017 with that quantitative reduction goal. The program partners expect to release this final report on November 30, 2017.

Materials Compatibility Issues with Airfield Pavement Deicers

To ensure safe airfield operations during winter weather conditions, airports must remove snow and ice from their paved surfaces. While mechanical means are preferred, chemical means to break the bond between frozen precipitation and the pavement surface and change the freezing point of fallen precipitation have long been used by airport operators.[3] For many years mixtures of ethylene glycol and urea were used, however, the resulting discharge of a defined hazardous material (ethylene glycol) and ammonia (a breakdown product of urea) caused significant regulatory burdens and adverse environmental consequences. Airports subsequently moved to more environmentally friendly chemicals consisting primarily of potassium and sodium acetates and formates. While these acetates and formates are more environmentally friendly than their pavement deicing predecessors, when used in large quantities or in close proximity to sensitive watercourses, runoff controls and mitigation measures may be necessary. New glycerin-based pavement deicing chemical have been introduced; however, the new products exhibit higher oxygen demands than existing products. Therefore, for those airports subject to stringent effluent limitations for discharges to receiving streams, additional best management practices (BMPs) and controls may be needed.

Recently, airline industry representatives have expressed concerns regarding acetate and formate-based pavement deicers due to excessive carbon brake oxidation from contamination by alkali metals such as potassium and sodium. While ongoing research is being conducted, some industry representatives suggest that moving away from acetate and formate-based materials and moving toward the glycerin-based materials as a likely solution to the carbon brake issue. As airports continue to be involved in the review of the carbon brake issue, ongoing evaluation of the likely environmental impacts from using a different chemical and the need for further mitigation to reduce potential water quality impacts should be evaluated on a case-by-case basis.

1.4.2.2 Postconstruction Stormwater

Stormwater management regulations and initiatives associated with construction exist at the federal, state, and local levels. These regulations generally focus on controlling stormwater runoff during construction; however, many states and local governments are emphasizing postconstruction stormwater management BMPs to reduce pollutant discharges and control flow to minimize erosion and downstream flooding.

Most airports with large impervious areas (parking lots, terminals, ramps, runways and taxiways) were developed prior to stormwater regulation associated with construction. As EPA imposes new standards and states and local governments expand their stormwater requirements to meet local needs and water quality improvement desires, airports find themselves in a challenging position of needing to rebuild or expand impervious infrastructure while meeting new stormwater rules requiring expensive and maintenance intensive BMPs. In some cases these BMPs are not only addressing new impervious areas and runoff management needs, but also addressing existing impervious areas which offer minimal stormwater management. The cost challenges are exacerbated by limited BMP options because ponds can be a wildlife attractant and are discouraged by FAA within 10,000 ft of an airport runway for safety reasons.

EPA has initiated several rule makings including the construction and development ELG and general permit renewals further tightening requirements associated with postconstruction stormwater runoff. In 2010, EPA entered into a settlement with the Chesapeake Bay Foundation to issue new stormwater rules further regulating stormwater flow. The draft rules were to be issued in June 2013; however, EPA has requested an extension and exact timeframes are unknown. Although EPA has not developed postconstruction rules, states and local governments are already making significant changes to stormwater management requirements that are affecting airports today.

States are issuing construction stormwater permits with postconstruction requirements. For example, the Ohio EPA already has rigorous postconstruction stormwater requirements. In addition to other requirements, Ohio EPA requires a permanent structural BMP that detains and treats site stormwater for sites over 5 acres. For redevelopment sites with no postconstruction BMPs installed, either a 20% net reduction of the site impervious area or treatment of at least 20% is required. Sites greater than 1 acre, but less than 5 acres, are required to implement postconstruction quality and quantity controls to meet the postconstruction stormwater management requirements and protect receiving streams from potential impacts of development.[4]

Local governments continue to expand their stormwater requirements through the Municipal Separate Storm Sewer Systems (MS4s) program. Under this program the following minimum control measures must be met:

- Public education,
- Public involvement,
- Illicit discharge detection and elimination,
- Construction stormwater management,
- Postconstruction stormwater management, and
- Pollution prevention–good housekeeping.

Many MS4s are developing and enforcing postconstruction stormwater programs to address local water quality and quantity challenges (e.g., flooding) and airports are often seen as significant contributors. As such, airport are often required to consider applicable controls including: pre- and postdevelopment peak flow restrictions, stream buffer requirements, water course protection and conservation easements, promoting in-fill development, and increasing open–green space.

1.4.2.3 Evolving Site-Specific Water Quality Considerations

A few airports have experienced site-specific water quality concerns that fall outside of the normal realm of parameters. Low levels of copper and zinc in stormwater runoff have the potential to adversely affect fish. In the Pacific Northwest, regulatory thresholds have been greatly reduced and airports and other industrial dischargers are being required to implement BMPs to control metals in stormwater discharges. As part of ongoing adaptive management for reducing metals in stormwater, the Port of Seattle applied two BMP strategies to reduce zinc and associated toxicity in roof runoff at Seattle–Tacoma International Airport. One roof was retrofitted with downspout media filters, while four others were painted resulting in a 37% to 70% reduction in zinc discharges from the roofs.[5] Reducing discharges of stormwater with low-level metals concentrations is an ongoing activity for airports in the Pacific Northwest and those facilities continue to development their adaptive management strategies.

The presence of nuisance levels of biofilms in streams receiving stormwater containing deicers has been identified as a regulatory concern at a handful of airports. The organisms comprising these biofilm communities are naturally occurring and ubiquitous in the environment, including downstream of many other common discharge sources. One challenge in this area relates to the application of state standards for water quality that speak subjectively of "nuisance bacteria." These standards do not quantitatively define the density of colonization that legally transforms a naturally occurring population into a prohibited nuisance. Even with an appropriate regulatory standard, the means of achieving that standard is uncertain due to lack of scientific knowledge about the combinations of factors that can foster prolific biofilm development. ACRP Research Project 02-32 was initiated in 2011 to identify the factors that most significantly promote or inhibit the development of environmental biofilms in association with airport deicing runoff. The products of this effort will include a summary of current knowledge, findings from field and laboratory experiments, and recommendations for further research.

1.4.3 FUTURE VISION

There is a need to develop aviation-specific research programs to address the following topics relating to water quality,

1.4.3.1 Aircraft and Pavement Deicing

- Accessible information on the achievable performance and practical limitations of technologies and practices for reducing amounts of deicers discharged to the environment.
- Mechanism for the industry to track the status of pavement deicer materials compatibility assessments being performed by others.
  - Guidance on best practices for approaches to NPDES permitting for stormwater associated with deicing activities, which would be helpful to airports as a way to gain insight from the successful experience of other airports facing similar permitting challenges. It should include the topic of how the deicing ELG does and does not apply to existing airports and serve as a resource for airports pursuing permit negotiations.
- Applied research products to support undefined needs of the Voluntary Pollution Reduction Program.

1.4.3.2 Postconstruction Stormwater

- Readily accessible inventory of state and local regulatory initiatives relating to postconstruction stormwater.

1.4.3.3 Evolving Site-Specific Water Quality Considerations

- Identification of trends and possible future research needs through tracking of evolving site-specific water quality considerations.

1.4.4 RESEARCH NEEDS

To help achieve the vision, airport sponsors, agencies, vendors, and other stakeholders are in need of research to address the following topics:

- Achievable performance and practical limitations of technologies and practices for reducing amounts of deicers discharges to the environment;
- Achievable performance and practical limitations of technologies and practices for reducing amounts of metals (zinc, copper, etc.) discharges to the environment;
- Inventory of state and local regulatory initiatives relating to postconstruction stormwater;
- Postconstruction stormwater control BMPs in a potential wildlife management context;
- Update of *ACRP Synthesis 6: Impact of Airport Pavement Deicing Products on Aircraft and Airfield Infrastructure*; and
- New research to assist the industry in responding to evolving site-specific water quality considerations.

1.4.5 ADDITIONAL RESOURCES

Amendments to Effluent Limitations Guidelines and Standards for the Construction and Development Point Source Category. Available at http://water.epa.gov/scitech/wastetech/guide/construction/index.cfm. Accessed May 29, 2013.

EPA Construction General Permit. Available at http://cfpub.epa.gov/npdes/stormwater/cgp.cfm. Accessed May 29, 2013.

Proposed National Rulemaking to Strengthen the Stormwater Program. Available at http://cfpub.epa.gov/npdes/stormwater/rulemaking.cfm. Accessed May 29, 2013.

Stormwater Discharges From Municipal Separate Storm Sewer Systems (MS4s). Available at http://cfpub.epa.gov/npdes/stormwater/munic.cfm. Accessed May 29, 2013.

1.4.6 CASE STUDY

1.4.6.1 Gerald R. Ford International Airport Application of *ACRP Report 14: Process for Developing an Integrated Deicing Runoff Management Program*

In the late 1990s, the Gerald R. Ford International Airport in Grand Rapids, Michigan, implemented a program to control the discharge of deicers in stormwater runoff through a combination of conservation practices, containment–collection, and glycol recycling. Over the past 5 years, approximately one-third of all applied glycol has been recovered and recycled. Although there have been no observed problems with dissolved oxygen or other water quality constituents in the stream surrounding the airport, in 2009 the airport was notified by the Michigan Department of Environmental Quality that nuisance biofilms were occurring in a small tributary stream to the Thornapple River, which receives stormwater containing deicers. The airport's NPDES permit was reissued in 2011 with the requirement for elimination of the airport's contribution to the nuisance conditions.

The airport undertook an evaluation of alternatives for eliminating its contribution to the occurrence of the nuisance biofilms following the principles and guidance described in *ACRP Report 14: Deicing Planning Guidelines and Practices for Stormwater Management Systems*. Steps in the process included:

1. Investigation of system performance required to achieve regulatory compliance;
2. Identification of all available technologies and practices that might be reasonably applied as part of an enhanced deicing runoff management system;
3. Objective evaluation of potential management alternatives using a tiered approach to narrow the analysis to the most promising and appropriate alternatives; and
4. Identification and refinement of the preferred alternative.

The resulting system design consolidates runoff from all aircraft deicing areas, diverts all stormwater flows away from the sensitive tributary stream, and routes of all contained deicing runoff through a natural treatment system prior to discharge directly to the Thornapple River.

NOTES

1. Effluent Limitations Guidelines and New Source Performance Standards for the Airport Deicing Category. 77 FR 29168, May 16, 2012.
2. 77 FR 29168, May 16, 2012.
3. http://www.airportimprovement.com/content/story.php?article=00194.
4. http://epa.ohio.gov/dsw/permits/GP_ConstructionSiteStormWater.aspx.
5. http://www.brownandcaldwell.com/technicalPapersAbstract.asp?TPID=6141.

2

Sustainable Solutions to Address Environmental Challenges

2 SUSTAINABLE SOLUTIONS TO ADDRESS ENVIRONMENTAL CHALLENGES

2.1

Climate Change Adaptation Planning and Preparedness

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2.1.1 INTRODUCTION

Recent weather events (record-breaking heat waves, drought, flooding and extreme storms) have increased some airports' awareness of the potential importance of planning for future climate conditions and associated weather risks to infrastructure and operations. This chapter presents background information on projected climate changes and weather, current government adaption initiatives, gaps in current design criteria, considerations regarding potential operational impacts, and describes a future vision of resiliency for airports. Recent research is also summarized, including a directly applicable case study and ongoing research needs.

Proactive assessment and the resulting mitigation measures to minimize risk of changing weather will minimize damage to infrastructure, interruption of operations, and economic losses. For airports, this means incorporating region-specific climate projections into existing and new airport planning processes can reduce the adverse impacts of climate change on infrastructure and operations while bolstering a region's ability to withstand and recover from future weather events or changes (i.e., become more resilient).

2.1.1.1 Important Definitions

Climate change adaptation planning and preparedness is a rapidly evolving subject of growing interest within the transportation community. For the purposes of understanding terms used in this document, below are example definitions of nine terms that are commonly used in climate change adaptation discussion and research.

Climate Change

A worldwide change referring to long-term and irrevocable shifts in climate, including temperature, wind, and precipitation and their seasonal patterns.

Climate Change Adaptation Planning and Preparedness

An activity undertaken by an organization to understand possible changes in climate, the likely effects of the change on infrastructure and operations. and the development of potential mitigation measures needed to respond to those changes to ensure minimal disruption. Proactive planning can be used to assess and minimize the risks associated with future climate change. Climate change adaptation planning and preparedness can be incorporated into existing planning process or can be initiated as a stand-alone activity. In either case it typically involves all departments and components of an organization. Climate change adaptation planning and preparedness typically begins with an evaluation of local climate change projections and their potential impacts on an organization's assets (e.g., infrastructure) and operations. The results of adaption planning may include a list of prioritized projects for the short-, mid-, and long-term horizons that are focused on reducing loss and improving resilience. The Airport Cooperative Research Program (ACRP) recently initiated research Project 02-40: Climate Change Risk Assessment and Adaptation Planning at Airports, which is intended to provide guidance and a tool to assist airports in conducting adaptation planning and preparedness.

Climate Change Projections

Climate change projections are the anticipated changes in climate as determined through scientific studies and models. To project future trends in climate, data is generated from general circulation models (GCMs) to describe anticipated changes in climate on the regional level. Downscaling methods are often applied to the models to generate specific climate projections on the state and local level. GCMs use various emission scenarios, which are based on different possible paths of global development, population growth, and reduction in greenhouse gas (GHG) emission rates. The projected changes in climate are used to identify associated impacts across a wide range of sectors, including transportation, water supply, agriculture, infrastructure, and natural resources (IPCC, 2007).[1] Climate change projections are the foundation of climate change adaptation planning and preparedness; although past weather patterns are typically used for planning purposes, the rapid changes in weather patterns makes the past data less effective for future planning.

Exposure

Exposure refers to the particular climate stressors or hazards faced by an organization, such as flooding, drought, extreme heat, changes to precipitation, sea level rise, and increased frequency and severity of storms.

Greenhouse Gases

A collective term referring to carbon dioxide (CO_2), methane (CH_4), nitrous oxide, sulfur hexafluoride, hydrofluorocarbons, and perfluorocarbons emitted from human activities and natural systems into the atmosphere and have collectively been determined to trap heat that would otherwise be released into space. GHGs are persistent and remain in the atmosphere for long periods of time; even if emissions ceased immediately. The GHGs that have been released over the last 50 to 100 years would continue to cause unavoidable climate change.

Resiliency

Resiliency is the capacity of an asset or system to absorb impacts while retaining essential processes combined with the speed of response and recovery.

Risk Assessment

Risk assessments are evaluations of airports' infrastructure and operations vulnerabilities associated with projected changes in climate. The traditional definition of risk is defined as "consequence of failure" multiplied by the "likelihood of failure". In terms of climate change, the consequence of failure refers to the magnitude or severity of the impacts of a climate stressor (e.g., increased flooding) and may include damage, deterioration, or temporary or permanent disruption. Likelihood of failure refers to how susceptible an asset or operation is to a climate stressor combined with how likely that stressor is to occur at the airport. Risk assessments take into account the uncertainty related to the likelihood of failure, which is often described using qualitative terms, such as low, medium, or high. Risk assessments support decision making related to the selection of activities that will be implemented to prepare for climate change.

Uncertainty

Uncertainty describes the variability in the climate change projections arising from the use of several GCMs and unknown parameters used in the models. Climate change projections generated from GCMs and the scientific research include a level of uncertainty that should be taken into account during a risk assessment. Uncertainty may also occur in assessment of magnitude or likelihood. For example, the Intergovernmental Panel on Climate Change (IPCC) concluded that human activities very likely contributed to:

- The observed rise in global surface temperatures and sea level rise;
- Changes in wind patterns, affecting extra-tropical storm tracks and temperature patterns;
- Increased temperatures of extreme hot nights, cold nights, and cold days; and
- Increased risk of heat waves, areas affected by drought since the 1970s, and frequency of heavy precipitation events.[2]

Vulnerability

The potential for loss from climate change stressors, including loss of operations and infrastructure. Vulnerability assessments evaluate the combination of exposure and resiliency of a particular asset or operation.

2.1.2 CURRENT STATE

2.1.2.1 Worldwide Airport Approaches to Adaptation

Airports around the world will be affected by climate change. Various organizations are working to advance understanding of these impacts and strategies to adapt to the changes. In particular, the

Airports Council International (ACI) published a report in 2011: Planning Airport Adaptation to Climate Change. This report highlights the impacts climate change may have on operations and safety as well as business at airports globally, and lists specific actions the ACI World Environment Standing Committee and individual airports should take to prepare for the impacts of climate change. Additionally, the International Civil Aviation Organization (ICAO), a specialized agency within the United Nations, also recognizes the impact of climate change on aviation and in 2010, included an adaptation chapter as part of their environmental report. This chapter examines the potential impacts of sea level rise, temperature change, and other climate change variables and discusses at a high level some of the international effort that has been conducted to research and understand climate change vulnerabilities and adaptation strategies.

While international support for research on climate change adaptation is helpful to address climate change challenges at a global level, due to varying impacts across geographical regions, individual airports will not be able to rely on global climate change research as they begin to make decisions regarding adaption needs. While understanding how the climate is changing on a global level and what other airports internationally are doing to adapt to vulnerabilities is important to inform potential adaptation strategies, there is also a strong need for downscaled research to better understand the projected impacts on specific locations.

Europe and U.K. Airport Efforts

EUROCONTROL, the European Organization for the Safety of Air Navigation, recently published the 2013 Challenges of Growth Task 8: Climate Change Risk and Resilience report. This report was the product of a survey sent to aviation stakeholders throughout Europe and a workshop hosted by EUROCONTROL to discuss climate change adaptation. The report indicates a broad consensus between European aviation stakeholders that action is needed to adapt to the impacts of climate change and recognizes that European aviation stakeholders are aware of the potential direct negative impacts of precipitation, water supply, sea level, and temperature increase issues on European airports.

In addition to EUROCONTOL's broad efforts, there are other country specific initiatives. For example, in 2008 the United Kingdom published a Climate Change Act which provides information about climate change and direction and guidance is a foundation for work on climate change adaptation within the United Kingdom. As part of the implementation of the Climate Change Act of 2008, the U.K. government was given the authority to ask organizations to produce Adaptation Reporting Power documents. In response to the Climate Change Act, 10 U.K. airports and the U.K. National Air Traffic System were asked to submit adaptation plans.[3]

U.S. Activities, Executive Order 13514, 2012 DOT Adaptation Plan

On October 5, 2009, President Obama signed Executive Order 13514 (EO 13514): Federal Leadership in Environmental, Energy, and Economic Performance. This order contains a provision for the incorporation of climate change adaptation into policies and practices at federal agencies. In accordance with the implementing instructions from the White House Council on Environmental Quality for EO 13514, the U.S. Department of Transportation (DOT) issued a Policy Statement on Climate Change Adaptation in June 2011. This policy statement commits the U.S. DOT and its modal agencies to "integrate consideration of climate change impacts and adaptation into the planning, operations, policies, and programs of DOT in order to ensure that taxpayer resources are invested wisely and that transportation infrastructure, services and operations remain effective in current and future climate conditions”.[4] The FAA supports DOT’s efforts to meet the goals it set forth in the 2011 Policy Statement. In 2012, DOT committed to three priority actions for implementation, tools, planning, and asset management. Following direction from DOT, FAA surveyed its own programs and needs and committed to three priority actions to address climate change, one for each of the three DOT action categories. These DOT and FAA actions were included in the 2012 Department of Transportation Climate Adaptation Plan*,* released for public review in February 2013.

The FAA tools action is the Common Support Services–Weather project. This is a data dissemination tool that will distribute unified weather information instantaneously across the NAS. This information will be used to increase efficiency in the air traffic system by better predicting where delays due to weather may occur. As the climate changes, better weather data are vital to ensuring efficient operations within the NAS.

The FAA planning action is called airport sustainability planning. The FAA is providing grants to selected airports to develop sustainability master plans or airport sustainability plans. Sustainability master plans incorporate sustainability considerations into an airport master plan. Airport sustainability plans are stand-alone documents that focus solely on sustainability. Both document types utilize a similar process: development of an airport sustainability policy, a baseline assessment of airport activities, and identification of initiatives that can make the airport sustainable.

Three of the 12 initial airports that received FAA funding for sustainability planning documents analyzed climate adaptation efforts. Each airport in the United States will be impacted differently by climate change. The FAA’s airport sustainably planning efforts enable individual airports to evaluate the potential effects of climate change they may face, anticipate site-specific vulnerabilities, and develop initiatives that will improve the resiliency of their infrastructure.

The FAA asset management action is a navigation infrastructure assessment studying how select navigation infrastructure may be vulnerable to storm surge from hurricane water inundation at 14 coastal study areas. It is vital to understand where vulnerabilities currently exist in order to plan correctly for future climate adaption needs.

Although only the planning action has a direct connection to airports, each of the FAA priority actions has airport applicability and will provide results that may benefit the entire aviation community.

North American Airport Activities, Synthesis 33 Case Studies, Coastal and Inland Examples

The *ACRP Synthesis 33: Airport Climate Adaptation and Resilience* was published June 18, 2012. This synthesis report evaluated climate change adaptation initiatives, challenges, and motivation for action based on the results from a survey of 20 airports to understand what the current practices are for considering climate change adaptation in airport planning. The synthesis includes eight case examples illustrating different airport climate adaptation actions in the state of Alaska; Jacksonville, Florida; San Diego, California; Atlanta, Georgia; Toronto, Ontario; Dallas and Fort Worth, Texas; and Jackson, Mississippi. An abstract from the Dallas case example is provided in Section 2.1.6.

Due to unique geography and climatic extremes, Alaska has been planning and adapting to climate change longer than most other areas in the United States. Because the state of Alaska is responsible for the aviation facilities that service more than 200 remote villages, there has been statewide integration of climate adaptation action in airport planning and development.

The other areas listed in each case example illustrate airport planning from a local or airport level for sustainability planning or vulnerability analysis. Of the airports that listed specific climate changes as potential vulnerabilities, there was consensus that flooding from storm surge and sea level rise at coastal locations or from increase precipitation at inland locations is a primary concern and challenge for adaptation planning. The case examples also highlighted the impact that severe or unusual weather can have on airport operations and the need to ensure that airport planning is sufficient to accommodate extreme weather events (i.e., 2005 Hurricane Katrina, 2011 snow in Dallas). The case examples also highlight existing programs that make airports resilient to some of the impacts of severe weather. More research is needed to better understand the site-specific vulnerabilities of airports to climate change based on downscaled climate change prediction modeling. There also needs to be a greater understanding of how airports and communities assess their vulnerabilities and prioritize their adaptation action.

2.1.2.2 Gaps in Infrastructure Design Criteria Based on Historical Events and Trends

Planners, engineers, and architects use the guidance and standards set forth by local, state, and national design criteria to meet or exceed the standard for providing for the public health, safety, and welfare risk. The historical data is used to develop design criteria appropriate for the region. For example, building codes, landscaping ordinances, and utility and asset design standards are developed based on the statistical analysis of historical weather parameters such as temperature, humidity, precipitation, and wind speed. For instance, Figure 1 demonstrates the temperature standard for evaluating heating, ventilation, and air conditioning (HVAC) systems by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE). Further, FAA publishes a variety of advisory circulars (ACs) used by the design community to guide the development of airports and to guide planning and operations at airports.

Since future weather events cannot be precisely predicted to support design of facilities and infrastructure, historical data has been and remains to be used to describe the future weather events and their resulting characteristics (e.g., depth of precipitation in a 24-h period).

Using historical data to develop a design standard founded on the assumption that what has happened in the past may lead to a false sense of security for designers and infrastructure owners and stakeholders as they plan for the future.

For instance, ASHRAE 55 is used in HVAC design to define the range of indoor environmental conditions acceptable for most occupants.[5] The standards for ASHRAE 55 are based on the relatively consistent regional temperatures and humidity observed in the past and have been used to develop the temperature and humidity standards demonstrated in Figure 2. Climate change research predicts shifts in temperature and humidity may occur and therefore, design standards that are implemented today may not be resilient enough in the future. Small steps, however, are being taken, and in 2012, the U.S. Department of Agriculture updated its plant hardiness zones in the United States based (in part) on climate change.[6]

Most climate change models indicate that there is a potential for changes in temperature, humidity, precipitation, and wind. A sample of a few potential effects on airport infrastructure due to climate change effects are indicated in Table 1.

Adaptation eventually could occur through the incorporation of resilience into future development of design standards. Stakeholders should begin to incorporate climate change adaptation and resiliency into design and planning now to provide a more resilient infrastructure for the future.

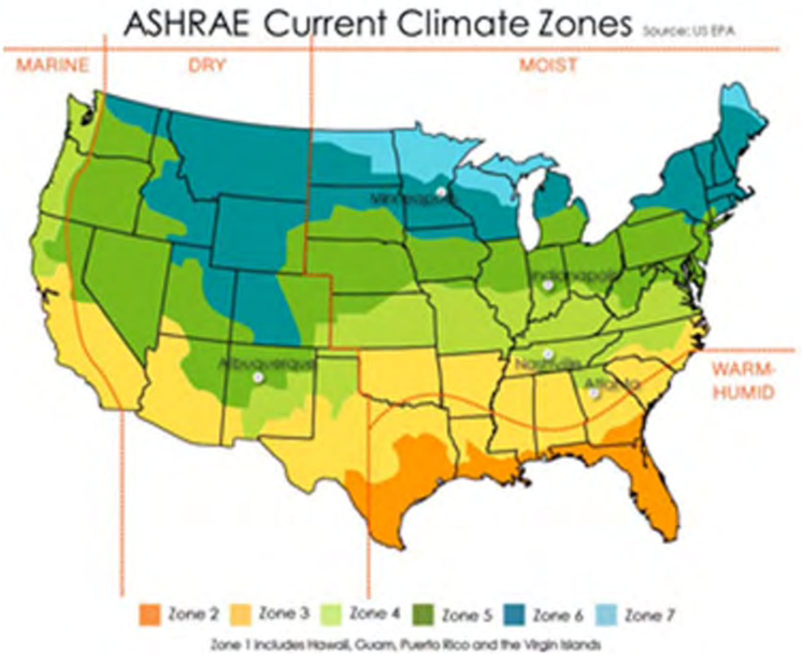

FIGURE 1 ASHRAE design standard for current climate zones.

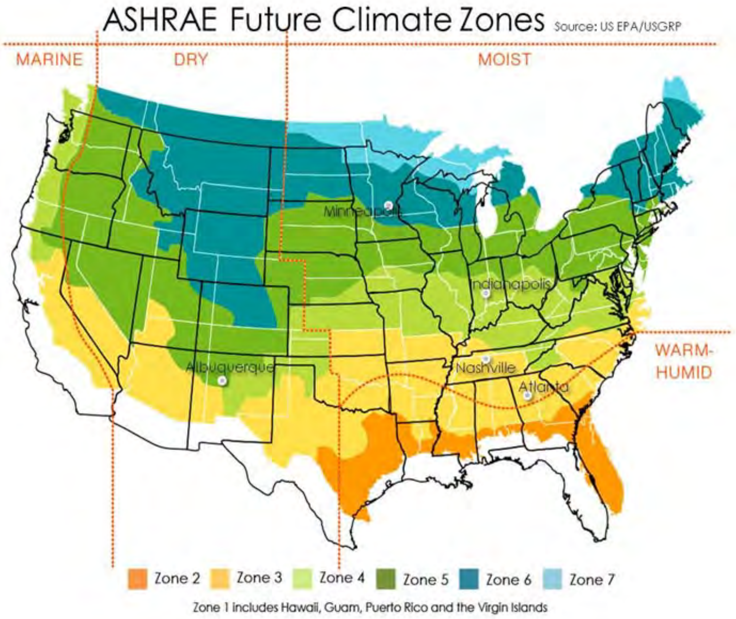

FIGURE 2 ASHRAE design standard for future climate zones.

TABLE 1 Sample Airport Operations and Assets That May Be Subject to Inadequate Resiliency Under Existing Design Standards

Airport Operation or Asset	Operational or Asset Component	Design Standard Affected by Climate Shift	Climate Change Shift
Deicing	Deicing activities, collection, and treatment	Rainfall frequency atlas[7] or intensity–frequency–duration	Temperature and precipitation
Drainage	Stormwater infrastructure	Rainfall frequency atlas or intensity–frequency–duration	Precipitation
Runways, taxiways, and holding areas	Pavement–soil stability	Rainfall frequency atlas	Precipitation
Buildings	Roofing and building materials	Snow load, wind load, window glazing, vapor barriers, corrosivity	Temperature, precipitation, humidity, wind
Buildings	HVAC	Temperature and humidity index	Temperature and humidity

2.1.2.3 Airport Operations Supporting Emergency Preparedness and Response

Airport operations are also susceptible to adverse weather and other nonweather-related events (e.g., terrorist threats). This susceptibility is further complicated by the fact that airports often serve as hubs for first responders in weather and nonweather-related disasters, which can be hundreds of miles from the primary disaster location. For example, when Hurricane Katrina struck the Gulf Coast, Jackson Evers International Airport in Jackson, Mississippi, which is approximately 3 h north of the coast, served as an emergency operations center for the first responders. It is even more complicated when looking at the National Airspace System where adverse weather events at a midwest airport can have ripple effects throughout the United States and leave passengers stranded at airports elsewhere in the country.

Planning for weather-related emergencies as well as those emergencies that could affect other areas of the country is not new to airport managers, FAA, or the U.S. Department of Homeland Security (DHS). However, as meteorologists predict weather changes in the future, airports' plans for future weather emergencies should also change. Emergency preparedness and response planning can take many different forms at an airport and most fall under a couple of categories generally integrating with the application of the National Incident Management System and Incident Command System. Airport emergency plans, continuity of operations plans, and irregular operations contingency plans are each used to address particular aspects of emergency response planning and a variety of guidance material is available for airport operators' use.

While most of the guidance documents and example plans address the types of weather disruptions that could occur and associated potential responses, few have yet to fully integrate disruptions exacerbated by weather phenomena induced by climate change (e.g., landing and takeoff weight restrictions during extreme high temperature periods). The full extent of effects is likely not fully understood. Significant additional research will be needed to vet and understand the impacts that may occur from climate change induced weather effects acting upon an airports future ability to operate efficiently.

2.1.3 CLIMATE CHANGE RESILIENCY: FUTURE VISION FOR AVIATION

Recent weather events have heightened public awareness of the possible impacts of climate change. According to a recent study by the Yale Project on Climate Change Communication, approximately 58% of Americans (about six in 10) believe that "global warming is affecting weather in the United States."[8] While this study indicates an understanding of the public, there remains an important opportunity to improve understanding within the aviation industry of potential impacts of climate change and to integrate these impacts into industry processes. Climate change projections should be incorporated into design guidance and emergency planning to increase the resiliency of the nation's aviation infrastructure. While adapting to the projected future climate is critical, this should also be coordinated with other GHG mitigation and sustainability initiatives.

In addition to ACRP Synthesis 33 discussed above, *America's Climate Choices: Adapting to the Impacts of Climate Change* from the National Research Council provides a comprehensive overview and uses transportation specific impacts from *TRB Special Report 290: Potential Impacts of Climate Change on U.S. Transportation*.[9] The aviation industry needs a clearinghouse of current impacts that all operators can draw on when making planning decisions.

Climate change projections and anticipated impacts can be integrated into planning, development, and design processes. An informative example of this in practice was at Oakland International Airport where sea level rise was included in the design requirements of a perimeter dike using a rough average of sea level rise modeling results. This added 12 in. to the dike design and this analysis also resulted in additional structural capacity included in the project to increase the height in future years.[10] The Port Authority of New York and New Jersey (PANYNJ) evaluates all capital projects using local climate change projections including increased temperature, increased precipitation and sea level rise. Based on local climate projections issued by the City of New York in 2009, where practical, the PANYNJ increases the design flood elevation for new projects by 18 in. to adjust for sea level rise.[11]

Adaptation and resiliency efforts should be coordinated with other development initiatives, especially sustainability programs. For example, in regions with projected increases in precipitation, green infrastructure can allow for flexible and changeable strategies for capturing and treating stormwater in an environmentally positive way. Alternatively, for regions with projected decreases in precipitation, water conservation programs can be accelerated to ensure that water resources will be used as strategically as possible.

2.1.4 OPERATIONS PERSPECTIVE

Aviation operations are particularly vulnerable to the impacts of climate change. Airport operations, and thus financial viability, are highly sensitive to adverse weather conditions and depend on fully functioning infrastructure. Climate change will pose a unique and diverse set of challenges and opportunities to airport operators that will be unlike those experienced by other industries or transportation modes.

Airport operations will be affected by both direct and indirect impacts. Direct impacts include consequences that occur within a short time period inside the airport geographical boundary and require actions or responses that are solely controlled by the airport operator. For example, increased frequency and severity of precipitation may result in the direct impacts of flooding and closure of runways and taxiways. Indirect impacts include consequences that result from either the climate stressor or the direct impacts over time, outside of the airport geographical boundary and often cannot be addressed through responses or actions by the airport alone. In the case of increased frequency and severity of precipitation, indirect impacts may include restriction of the movements of goods and people to and from the airport due to damaged surface transportation infrastructure, loss of power, and damaged relationships with customers who may perceive that the airport is at fault for their restricted travel options.

Climate change adaptation planning and preparedness will have both subtle and overt effects on airport operations, infrastructure, and overall economic well-being. Because adaptation planning is often conducted on longer-term horizons than typically seen for airports and there is uncertainty related to the projected changes in climate, the task of developing, implementing and monitoring adaptation activities can be a challenge for airport operators and decision makers. Currently, changes to airport operations due to changing climate trends are often done in a reactive manner without a thorough evaluation of potential consequences. Airport operators need additional information and a proven adaptive planning approach in in order to assess and minimize risk.

2.1.5 RESEARCH NEEDS

- Greater understanding of the potential changes from climate change particularly for extreme short-duration events.
- Greater understanding of the full extent of climate change-induced weather effects on an airports ability to operate efficiently in the future.
- Improvements in the confidence of climate change projections particularly for extreme short-duration events.
- Greater understanding of site-specific vulnerabilities of airports to climate change based on downscaled climate change prediction modeling.
- Greater understanding of how airports and communities assess their vulnerabilities and prioritize their adaptation action.
- Development of a systematic planning framework that airports can use to incorporate climate change adaptation planning and preparedness into new and existing planning processes.
- Best practices for adapting to various climate change variables; research on current adaptation strategies and a central repository for these.
- Assessment of the effectiveness of adaptation strategies that have been implemented.

2.1.6 CASE STUDY

2.1.6.1 Dallas and Fort Worth, Texas

The following case study is an abstract of the case study for Dallas–Fort Worth International Airport (DFW) as presented in *ACRP Synthesis Report 33: Airport Climate Adaptation and Resilience: A Synthesis of Airport Practice*.

DFW encompasses more than 18,000 acres, making it the second largest airport in the United States in terms of land area. It has five terminals, seven runways, and its own post office, zip code, and public services. DFW is the fourth busiest airport in the world in terms of aircraft movements. In recent years, DFW has managed several weather-related risks to its business and operations, including an unusual snow event, regional water scarcity, and operating in an area not meeting federal air quality standards. These events have raised awareness of climate risks and the effects climate changes can have on other activities, such as regulatory compliance. At the same time, DFW has a $1.9-billion renovation and expansion initiative underway, with an expected completion date in 2017. Three cases described here demonstrate the growing awareness of climate risks to DFW and to its growth, as well as its increasing capacity to address those risks.

The first case arose when, on February 4, 2011, the Dallas region received 2.6 in. of snow, just 2 days before the Super Bowl. As a result, more than 300 arriving flights were canceled at DFW, a hub for American Airlines. The Southwest Airlines hub, Dallas Love Field, closed temporarily. As a result, thousands of football fans were left in limbo, making for a major public relations problem that was a potential threat to DFW's reputation and business goals.

At DFW, runways and taxiways could not be cleared quickly enough because the existing snow and ice removal equipment had significant limitations; the existing equipment could only clear one of DFW's seven runways in 1 h after a deicer had been applied. Based on this severe limitation and actual events, DFW developed a strategy with a set of objectives designed to meet certain snow and ice removal requirements but did not follow a review of climate change projections. However, the recent event's impacts caused DFW to re-examine its capability. DFW obtained information from peer airports experienced in addressing ice and snow events, including those in Atlanta, Denver, Minneapolis–St. Paul, Chicago, and Boston.

As a result, DFW selected a set of equipment upgrades that enables it to clear three runways in 14 min for a 2-in. snow event, with a cost of $10 million for the new equipment, and $3 million for a storage facility, as well as $560,000 annually for operations and maintenance. This case demonstrates the significance of a single, catalyzing event, and it is clear that DFW rebounded quickly. This equipment upgrade makes the airport more resilient to at least one climate risk: the extreme winter weather projected to occur more frequently in the future.

The second case at DFW relates to more-frequent drought. The airport also experiences consecutive days of temperatures above 100°F, and has implemented water use restrictions during the past few years. As a result, water conservation measures at DFW have severely limited the use of water for irrigation, pavement power washing, and natural gas well drilling and fracking. Also, the Central Utilities Plant at DFW uses potable water in its cooling towers, because the airport cools approximately 700,000 gal of water per night to keep terminals air conditioned during the hottest part of the day. A terminal expansion will increase annual departures by 7,500 as early as 2014, significantly adding to annual water needs.

As the City of Fort Worth planned for the development of a new reclaimed water facility, it was clear DFW would be the majority user of the water. Reclaimed water—which is waste water processed to a nonpotable standard acceptable for industrial and other uses not affecting human health—has a stigma that can be difficult to overcome. Additionally, although reclaimed water is not as expensive as potable water, an appropriate rate needed to be set for the city to justify the project. In March 2008, the DFW board authorized the negotiation of cost sharing or set rates for the time when the water would be available and delivered to DFW. DFW, as well as the cities of Dallas and Fort Worth, agreed that the use of reclaimed water for nonpotable water usage at the airport was a prudent initiative based on the continuing North Central Texas region's extreme drought conditions and scarcity of water resources.

In September 2009, the DFW board approved the agreement reached with the city and $18 million in funding. The justification for these decisions was that reclaimed water would provide a long-term, less-expensive, and sustainable water supply and that its substitution for potable water would provide economic and environmental benefits to DFW and the region. DFW also justified the expense on the basis that an additional water supply would provide service reliability and reduce demands on existing water supplies and infrastructure. DFW calculated that the airport would save $4 million in costs over 20 years, and $121 million more over 60 years. DFW also cited drought resistance as an anticipated but nonquantified benefit. However, DFW's major tenant airlines needed to be convinced.

In 2011, the region experienced the worst drought on record, which justified proceeding with this initiative. Despite the prominence of the water scarcity issue, the initiative, as with the winter storms case, was not developed or discussed as a climate change adaptation measure.

The third case at DFW relates to the projected increases in regional temperature. DFW is undertaking a $1.8-billion terminal expansion and renovation initiative. Projects under this initiative are subject to environmental compliance review, including those covering federal and state air quality requirements. Early in 2011, the North Central Texas region was downgraded by the U.S. Environmental Protection Agency (EPA) to "serious non-attainment" under federal air quality standards. In effect, this air quality compliance issue could stall the expansion. Increased temperatures under climate change are likely to increase nitrogen oxides and volatile organic compounds emissions. For example, the EPA estimates that a 10°C increase in temperature doubles emissions of these pollutants.[12] For the short term, DFW will work through its air quality issues; however, the exacerbating effect of climate change on regulatory compliance is directly influencing the thinking of DFW personnel.

2.1.7 ADDITIONAL RESOURCES

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2 SUSTAINABLE SOLUTIONS TO ADDRESS ENVIRONMENTAL CHALLENGES

2.2

Natural Resource Management

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2.2.1 INTRODUCTION

Three topics have been identified as natural resource management issues facing airports today: wildlife hazard management, natural resource revenue generation, and water conservation.

2.2.1.1 Wildlife Hazard Management

The FAA has made significant strides in establishing wildlife hazard assessments (WHA) and wildlife hazard management plans (WHMP) at U.S. commercial service airports (FAR Part 139 certificated facilities). To date, the majority of FAR Part 139 airports have conducted a WHA and completed a WHMP and the remaining airports are either in the process of conducting a WHA–WHMP or have programmed funding to conduct these assessments and develop plans in the near future. While the FAA still provides guidance and project funding for FAR Part 139 airports to address ongoing challenges and implement WHMPs, there has been a new focus on the requirements of general aviation airports to conduct WHAs and potentially develop WHMPs. A number of general aviation airports have proactively conducted WHAs and developed WHMPs to address wildlife hazard issues at their facilities but the FAA does not have regulations or guidance in place to address requirements for general aviation airports. In December of 2012, the FAA published a clarification of applicability for airports that received federal grant-in-aid (including general aviation airports) in regards to wildlife hazard management requirements.[1] Under this Federal Register clarification, as well as certain revised FAA Advisory Circulars (ACs), general aviation airports could conduct either a WHA or a wildlife hazard site visit (WHSV), depending on their annual operations or based jets.

2.2.1.2 Natural Resource Revenue Generation

Many airports have natural resources on, below, or above their property. Traditional use of natural resources for revenue generation included timber harvesting, limited mineral extraction, fill material excavation, and drilling for oil. In recent years, less traditional natural resource revenue generation has increased at airports due to both financially viable technology and the ongoing challenge for airports to develop nonaviation revenue streams. These projects include gas wells, solar farms, wind turbines, water storage or treatment areas, aquifer storage recovery systems, mitigation areas, agricultural, and mining. While these projects are first reviewed for compatibility and safety related to aviation operations, the overall challenges (environmental and nonenvironmental) are unknown or unanticipated.

2.2.1.3 Water Conservation

Water is becoming an increasingly scarce and valuable resource in most parts of the United States. The U.S. Drought Monitor shows more than half of the contiguous United States as being in moderate to exceptional drought conditions.[2] In many portions of the country, 2012 was among the driest years on record (IPCC, 2012).[3] The combination of persistent drought conditions and a growing population that demands greater volumes of water for domestic, industrial, and agricultural uses has driven the need, and even mandates in many regions, for conservation practices that minimize waste and maximize the effectiveness of water that is available.

Airports in regions where water is scarce are seeing the need to reduce water usage across all of their operations, addressing uses such as drinking water, sanitary purposes, landscape irrigation, and rental car washing.

2.2.2 CURRENT STATE

In 2012, the FAA drafted three ACs related to wildlife hazards at airports, currently under circulation for review and comment. Two of these drafts revised existing ACs, and the third is a newly developed AC to clarify the protocol for conduct and review of WHAs, WHSVs, and WHMPs. The two revised, existing ACs were

- FAA AC 150/5200-33: Hazardous Wildlife Attractants on or Near Airports; and
- FAA AC 150/5200-32: Reporting Wildlife Aircraft Strikes.

The new AC mentioned above is FAA AC 150/5200-XX: Protocol for the Conduct and Review of Wildlife Hazard Site Visits, Wildlife Hazard Assessments, and Wildlife Hazard Management Plans. This new AC introduced the term WHSV which is intended to apply to general aviation airports (pending finalization of general aviation requirements and guidance under review).

Currently, both FAR Part 139 and general aviation airports are awaiting the outcome of FAA's review and consideration of the comments provided to the FAA on the three draft ACs and the Federal Registry notice (December 2012) to understand future requirements and applicable guidance to their facilities. To date, no new funding mechanism has been identified for either new requirements at FAR Part 139 airports or new requirements at general aviation facilities.

2.2.2.1 Natural Resource Revenue Generation

Airports are looking to new nonaviation revenue generation projects to offset operating costs. Currently, there is no resource for airport managers and decision makers to reference when evaluating natural resource revenue generation at their airport.

2.2.2.2 Water Conservation

Water conservation is a topic of significant interest globally, and the bulk of the research and technical development of water conservation practices occurs in settings outside of the aviation context. As a result, a large body of knowledge and information on the topic is available to airport operators from outside sources.

In the aviation context, water conservation programs were identified and described as part of a series of case studies of sustainability practices at 19 North American and European airports in *ACRP Report 80: Guidebook for Incorporating Sustainability into Traditional Airport Projects*. Case study examples of relevant practices fall into the categories of administrative aspects, site management, and water efficiency. The report provides guidance on how sustainable water strategies can be incorporated into traditional airport projects. Water conservation is also touched upon in *ACRP Report 33: Guidebook for Developing and Managing Airport Contracts* and *ACRP Synthesis Report 10: Airport Sustainability Practices.*

The 2012 ACI–North America Environmental Benchmark Survey (in press) reported that more than 60% of the responding member airports had water conservation programs in place, and about half of those programs had defined water use reduction goals. A small number of responding airports reported having a reduction goal but no formal conservation plan.

2.2.3 FUTURE VISION

2.2.3.1 Wildlife Hazard Management

The future vision of WHM at U.S. airports is to ensure that airports are provided practical guidance, applicable regulations, and funding to reduce aircraft–wildlife strikes. Understanding the operational and financial constraints related to proposed guidance and applicability clarifications for general aviation airports will be essential to affected airports. Airports also need educational outreach materials for stakeholders, governmental entities, and the public to explain why WHM is necessary and what steps the airport takes to balance safety and environmental concerns.

2.2.3.2 Natural Resource Revenue Generation

Airports need to improve understanding of the impacts, challenges, and accomplishments of natural resource revenue generation projects at airports.

2.2.3.3 Water Conservation

To respond to water conservation needs, airports require an understanding of the principles of water conservation, the options that are available in an airport context, and the process by which a practical and effective airport water conservation program can be built and implemented.

2.2.4 RESEARCH NEEDS

The research needs presented below were identified to help achieve the vision described above in each of the topic areas.

2.2.4.1 Wildlife Hazard Management

- Develop a gap analysis to determine what wildlife hazard issues or challenges are not addressed by current industry practice, current–affordable technology, or applicable research.
- Provide research on the integration of WHM into the safety management system process.
- Develop an airport guide to developing WHMP educational outreach materials for stakeholders, governmental entities (local, state, and federal), nonprofit organizations, and the public.
- Work cooperatively with the FAA and potential state DOT agencies to identify funding mechanisms for the proposed new requirements at general aviation airports and for ongoing management requirements.

2.2.4.2 Natural Resource Revenue Generation

- Develop a resource document–guidebook that provides airport managers and decision makers with examples, lessons learned, strategies, and checklists to evaluate natural resource revenue-generation projects.

2.2.4.3 Water Conservation

- Develop industry guidance on planning water conservation efforts tailored to aviation facility-specific context and need.
- Establish industry metrics for setting goals and assessing progress of water conservation efforts.
- Provide guidance on methods to quantify and track water usage in an airport context.

2.2.5 ADDITIONAL RESOURCES

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2 SUSTAINABLE SOLUTIONS TO ADDRESS ENVIRONMENTAL CHALLENGES

2.3

Renewable Energy

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2.3.1 INTRODUCTION

The International Energy Agency defines renewable energy as being "…derived from natural processes that are replenished constantly. Solar, wind, hydro, and some forms of biomass are common sources of renewable energy."[1]

Energy security and climate change, coupled with high fossil fuel prices and the specter of peak of production of conventional oil concerns (extreme supply shortages), are driving public policy to increase renewable energy through manufacturing and generation incentives and long-term production mandates and goals.[2] In 2011, the Intergovernmental Panel on Climate Change, the world's leading climate scientists convened by the United Nations, said "…as infrastructure and energy systems develop, in spite of the complexities, there are few, if any, fundamental technological limits to integrating a portfolio of renewable energy technologies to meet a majority share of total energy demand in locations where suitable renewable resources exist or can be supplied."[3] According to the Renewable Energy Policy Network for the 21st Century, renewable energy replaces conventional fuels in four distinct areas: electricity generation, hot water–space heating, motor fuels, and rural (off-grid) energy services.[4] The first three areas are directly applicable to airports.

According to the Federal Energy Regulatory Commission's Annual infrastructure update report, 49% of all new electricity generation facilities constructed in the United States in 2012 were from renewable energy. As depicted in Figure 1, continued growth in wind power was the leader with 41% of the total and solar power comprised 6%.[5] In fact, wind power has generated more than one-third of all new electricity generation in the United States since 2007. Significant progress towards a renewable energy transition has been made over the past 5 to 7 years.

The Energy Hierarchy is a classification of energy options prioritized to assist progress towards a more sustainable energy system.[6] The highest priorities cover the prevention of unnecessary energy usage both through eliminating waste and improving energy efficiency. The sustainable production of energy resources is the next priority. Nonsustainable and waste-producing energy generation options are the lowest priority.

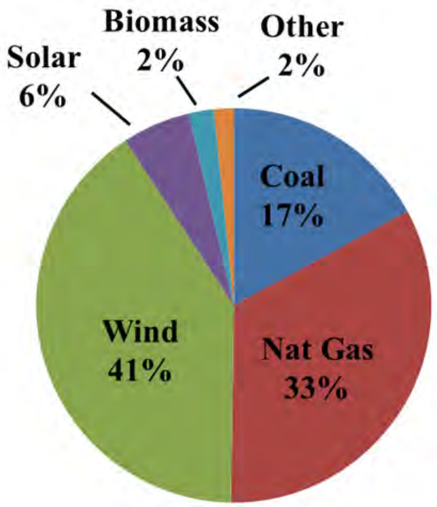

FIGURE 1 New sources of U.S. electricity, 2012.[7]

Priority 1. Energy conservation. The reduction or elimination of unnecessary energy use.

Priority 2. Energy efficiency. Efficiency improvements, ranging from improving the efficiency of a television through to that of a coal-fired power station, are usually achieved through the application of engineering principles.

Priority 3. Exploitation of renewable, sustainable resources. As well as resource availability, effective and sustainable energy provision must also embrace wider issues such as affordability, societal acceptability and environmental impact.

Priority 4. Exploitation of nonsustainable resources using low-carbon technologies.

Priority 5. Exploitation of conventional resources as we do now. While perpetuating the current approach may be understandable from an economic perspective, it will have unsustainable local and global impacts, hence its lowest position in the Energy Hierarchy.

While energy efficiency often provides the most cost-effective way to limit energy usage and thereby reduce both cost and environmental footprint, the only way to achieve a net zero objective is to generate emission-free renewable energy.[8]

2.3.2 CRITICAL ISSUES

Some of the critical issues airport managers need to address when considering if and how to apply renewable energy options at their airports are:

1. **Drivers.** What factors are driving the consideration of renewables (environmental, economic, security, political, regulatory, or some combination)? These factors will define the scope and definition of success for any project or initiative. Regardless of the drivers, approach renewable energy as a long-term commitment as many of its benefits accumulate over time.
2. **Technology.** What are the naturally available renewable energy sources close to the airport, and are there proven and demonstrated technologies that have been applied locally or

regionally to convert them to useful power? Consideration of all potential technologies related to available natural resources is needed regardless of current status since technologies and public policy incentives can change quickly.

3. **Compatibility.** How does the airport assess the compatibility of renewables with airport infrastructure, function, and core business? The answer to this question starts with airspace safety and effects on navigation infrastructure and also addresses financial considerations and day-to-day logistics. Effective planning will help sort out the geographic factors that make some areas of the airport more suitable for renewable energy than others.
4. **Environmental impacts.** How does the airport assess and characterize the environmental impacts and benefits of renewable options? Consideration should be given to full life-cycle analyses including extraction, manufacturing, installation, operations, maintenance, and deconstruction.
5. **Community and social.** What does the surrounding community expect from the airport in terms of energy management and renewables? What is the airport's role when it comes to renewable energy and the community: leader, partner, or demonstrator? Community engagement should be included as part of the renewable energy planning.
6. **Financial impacts.** How does the airport analyze the economic and financial aspects of a renewables strategy or project? Does the strategy or project stand on its own financially? Use of a cost–benefit approach which could account for a variety of short- and long-term factors associated with changes in government subsidy programs, life-cycle costs, social and community effects, and carbon mitigation and other externalities.
7. **Carbon and renewable energy credits.** What is the airport's strategy to manage the issue of credits? Credits should be considered as a potential asset and weight given to the unpredictable nature of the credits market, its governance and administration, the banking of credits, and how the airport needs to account for credits.
8. **Airport capacity and expertise.** Does the airport have the capacity, with internal staff (engineers, lawyers, finance, maintenance, etc.) or the right partners to plan, design, install, operate, maintain, and deconstruct a renewables system? Expertise and time to manage the system from beginning to end should be considered along with the role of the airport during these phases. Alternatives should be evaluated like third-party ownership and associated cost savings and risk mitigation advantages.
9. **Decision-making tools.** Does airport management have the expertise and analytical tools to make an informed decision about a renewables strategy or project? The long-term nature of the strategy or project should be considered along with the wide range of variables and uncertainties that influence the alternatives, the recommendations, and the decision to invest in a strategy or project.

2.3.3 CURRENT STATE

2.3.3.1 State of Practice

A few renewable energy technologies have been implemented at airports, with solar photovoltaic (PV) installations being the most widely deployed. An informal count of solar PV on airport property in the United States has identified 43 airports hosting solar in 17 different states as shown in Figure 2.[9] The majority of these projects are owned by private entities that lease airport land and sell power into the electrical grid. The financial benefit to the airports from these business arrangements come from lease payments for use of property (land or buildings) or electricity cost discounts contracted through long-term power purchase agreements to acquire the electricity produced. The development of privately funded projects is concentrated in states that have enacted financial incentives to encourage the solar industry. States where such incentives have been passed and solar development has occurred at airports include California, Colorado, Massachusetts, and North Carolina.[10]

The FAA has also funded several solar projects using discretionary set-aside funds through the Voluntary Airport Low Emissions (VALE) Program and the new FAA Energy Efficiency Program. The FAA has recently stated that VALE will no longer be used to fund solar PV and funding for airport-owned facilities will be directed through the new program established in the FAA Modernization and Authorization Act of 2012 upon successful completion of an energy assessment.

VALE has also been used to fund a handful of geothermal projects associated with new terminal construction. While geothermal technology can directly tap energy sources close to the Earth's surface, projects that have been funded are known technically as ground source heat pumps, which utilize the constant temperature of the earth to pre-heat and pre-cool air or water which reduces the amount of energy required for traditional heating and cooling.

A few airports have installed wind power installations. These tend to be small building-integrated systems that are compatible with FAR Part 77-defined airspace. There is one example of a larger wind turbine at Burlington International Airport in Vermont and a prototype of a medium-sized wind generator operating at Martha's Vineyard Airport in Massachusetts.

FIGURE 2 Solar projects at U.S. airports.

2.3.3.2 Research

Industry research has continued to focus on two particular areas: compatibility and economics. ACRP Project 02-38: Guidebook for Energy Technologies Compatibility with Airports and Airspace commenced in May 2012 as a follow-up to *ACRP Synthesis 28: Investigating Safety Impacts of Energy Technologies on Airports and Airspace*. The research is focused on developing siting and best-practice guidance for a variety of energy technologies operating near airports including solar, wind, oil and gas drilling, power plant stacks and cooling towers, and electric transmission infrastructure. Applied research being conducted under the project includes reflectivity testing of commercially available solar panels and surveying pilots for their experiences with airport solar projects. The guidebook is expected to be released at the end of calendar year 2013 and will be useful to airport staff, aviation stakeholders, and energy professionals in siting new projects.

ACRP Project 01-24: Renewable Energy as an Airport Revenue Source is a recently awarded research study that will focus on the potential financial benefits of deploying renewable energy. The two mechanisms for financial benefit are revenue as income derived from annual payments and cost savings earned from energy discounts and a reduction in electricity procured from commercial suppliers. The project will explore the role and structure of government incentive programs, new FAA funding mechanisms, and traditional bonding programs. The project is scheduled for completion in 2014.

The FAA continues to collaborate with other federal agencies on research to protect airspace safety from potential impacts from renewable energy projects. The FAA has recently provided for limited release the Solar Glare Hazard Analysis Tool (SGHAT) developed by the U.S. Department of Energy's (DOE's) Sandia National Laboratories. SGHAT allows project planners to assess the potential for an ocular hazard from a proposed solar facility on a sensitive airport receptor such as the air traffic control tower or an aircraft on final approach. Sandia is also implementing the Interagency Field Testing and Evaluation (IFT&E) Program working with the U.S. Department of Defense and DHS, and the National Oceanographic and Atmospheric Administration. IFT&E is conducting field trials of radar mitigation technologies that can be deployed to correct potential clutter impacts of wind farms on radar communication.

2.3.3.3 Policy

The FAA published the *Technical Guidance of Selected Solar Technologies on Airports* (also referred to as the Solar Guide) in November 2010 to provide the aviation and energy industries with a single reference for airport solar projects. After glare impacts were identified from a solar project at Manchester–Boston Regional Airport in May of 2012, the FAA placed a cautionary notice on the cover of the Solar Guide indicating that additional requirements for studying glare may be required for future projects. A formal update to the Solar Guide may be forthcoming; however, the most substantial change in policy relative to solar guidance is expected to be a requirement that sponsors provide the FAA with reflectivity modeling using SGHAT, including analysis of potential impacts to specific sensitive receptors.

The FAA's Obstruction Evaluation (OE/AAA) office will continue to review applications for projects that may have a physical or nonphysical impact on airspace under FAR Part 77. The OE/AAA has had a tremendous increase in applications in recent years from wind farm developers due to the fact that each typical wind turbine constructed in the United States exceeds the 200-ft (above-ground level) trigger for filing a Form 7460 with the FAA under Part 77. Due to concerns that wind project developers were erecting meteorological towers (also referred to as "met towers" that are necessary for identifying wind power project sites) at heights under 200 ft to avoid filing form 7460 and protecting the confidentiality of projects sites from competitors, the FAA announced a voluntary obstruction lighting program for met towers in January 2012. Low-flying aircraft such as crop dusters and helicopters are most at risk and at least one fatality associated with a collision with an unmarked and unnoticed met tower has occurred in recent years.[11]

The FAA is also updating its *Land Use Compatibility Planning Advisory Circular* which is expected to be released in 2014. The Land Use AC provides guidance on compatible land uses around airports and may consider including guidance on energy technology projects. *Interim Guidance on Land Use in the Runway Protection Zone* (RPZ) issued in September 2012 specified new proposals to locate electricity infrastructure including solar panels in the RPZ requires airport sponsors to consult with both the regional office and FAA headquarters.

2.3.3.4 Tools

There are a number of publicly available tools to help stakeholders structure a business case for renewable energy projects. While many of these tools have not been developed specifically for use in the airport context, they can be adapted to reflect conditions particular to an airport operator. These tools include

- **Cost of Renewable Energy Spreadsheet Tool (CREST).**[12] This spreadsheet-based cash flow model, developed by the National Renewable Energy Laboratory (NREL), aids users in the economic assessment of renewable energy projects as well as in the design of cost-based incentives to support those projects. CREST assists with analysis of solar (PV and solar thermal), wind, geothermal, and anaerobic digestion technologies.
- **Vehicle and Infrastructure Cash-Flow Evaluation (VICE) model.**[13] This tool, also developed by NREL, helps users evaluate the profitability of compressed natural gas (CNG) projects. VICE is structured to compare the relative economics of running vehicle fleets on CNG or diesel. It computes operating and capital costs for both vehicles and refueling infrastructure.
- **GHGs, Regulated Emissions, and Energy Use in Transportation (GREET) model.**[14] This tool, developed by Argonne National Laboratory, computes the life-cycle environmental footprint of more than 80 vehicle–fuel systems. GREET can compute consumption of total energy, emissions of GHGs [e.g., carbon dioxide (CO_2) and CH_4], and emissions of six criteria pollutants. It has a module specifically designed to compute life-cycle emissions for aviation alternative fuels.
- ***ACRP Report 83: Assessing Opportunities for Alternative Fuel Distribution Programs.***[15] This report is a guidebook and toolkit to help airports examine the potential to introduce alternative fuels for both air and surface transportation. It describes the different technical, environmental, financial, social, and regulatory considerations to keep in mind when developing alternative fuel projects at airports.

2.3.4 FUTURE VISION

The question is not whether renewable energy can be successfully deployed at airports—the current state makes it clear that solar use is fairly widespread—but how to efficiently assess site-specific opportunities and effectively plan to facilitate accelerated deployment on a large scale. The future vision is one in which airports are well aware of renewable energy as a fundamental component of economic and environmental success, and have the tools and resources available to respond to public and private sector-initiated opportunities. The future vision includes these key actions:

- **Renewable energy planning.** Development of planning guidance for airports as a roadmap to implementing their renewable energy programs. The guidance should include
  1. Evaluation of suitable renewable energy technologies given the area's natural resources and the airport's energy needs;
  2. Identification of site-specific locations for deployment considering existing utility infrastructure network and airspace compatibility issues;
  3. Preparation of financial planning blueprints for public-sector investment and private partner alternatives accompanied by simple examples of airports that have successfully followed such programs; and
  4. Analysis of long-term operations and maintenance options for the energy technologies used for planning internal airport capacity expertise and informing long-term projects costs.
- **Enhancement of existing siting and financial tools.** Development of airport modeling tools to help them prepare their renewable energy planning program and assess site-specific opportunities as they become available. Some modeling tools should be specific to evaluating the compatibility of technologies with core aviation activities. Others should integrate with financial planning to consider state- and local-specific renewable energy incentive programs as well as changes in technology efficiency and component costs that have a fundamental effect on financial feasibility analysis. Some of these tools are currently available in various forms, however, none are currently matched with the needs of airports.
- **Outreach to airports.** While a few airports have successfully developed repeatable renewable energy programs, the majority of airports remain skeptical that renewables can provide both environmental and economic benefits to the airport business. Research into the financial factors that have contributed to the successful projects and the communication of that information is needed to bring renewable energy into mainstream thinking to encourage airports in developing renewable energy plans, so that they can be ready when the financial opportunity is presented.

2.3.5 RESEARCH NEEDS

The nexus between energy and airports was, until fairly recently, an unexplored topic. A number of research projects undertaken over the past few years have greatly expanded the knowledge base of renewable energy and airports, and have helped to narrow down the remaining data gaps. The following three research items have been identified as near-term priorities to help facilitate the next stage of renewable energy deployment.

- **Integration of renewable energy into existing planning tools** including sustainable master plans and airport layout plans. This project would build on a broader planning need and fold in the renewable energy planning components discussed in this e-circular.

- **Expanding the SGHAT modeling tool** to include data from specific solar panel modules. This project would advance the functionality of the SGHAT by integrating initial data collected under ACRP Project 02-38: Guidebook for Energy Facilities Compatibility with Airports and Airspace on commercially available solar modules and providing reflectivity data inputs through the selection of a manufacturer and model in SGHAT. This will initially require an expansion in the reflectivity data collection program.
- **Develop the opportunity to grow biofuels on airport land** to support biofuel production hubs. This research topic would dovetail with industry efforts in alternative fuels and agricultural feedstock production by building on recent research that has suggested that biofuel crops can be safely harvested on airfield land without increasing potential wildlife attractants.

2.3.6 CASE STUDY

The SGHAT was developed by the DOE's Sandia National Laboratories to assess the potential impacts of glare from solar power projects on airport sensitive receptors.[16] Since early 2013, the FAA has been directing airport sponsors and their energy partners to use SGHAT to evaluate if proposed projects will result in an ocular hazard to air traffic controllers and pilots on final approach. The tool is accessed on the Sandia National Laboratories' website. Users locate the airport site using an interactive Google Map. They can draw a polygon where the solar panels are proposed and insert design parameters including panel tilt angle, compass orientation, and height. Then an observation point is selected to evaluate whether glare would be seen and how intense it would be. The model processes the sun's path throughout the year and calculates the corresponding glare and if it interacts with the observation point. The requirement to use SGHAT is expected to be included in upcoming guidance from the FAA. SGHAT provides the FAA, airports, and their energy partners with a means for quickly and accurately assessing glare impact which will result in more projects and fewer impacts.

2.3.7 ADDITIONAL RESOURCES

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2 SUSTAINABLE SOLUTIONS TO ADDRESS ENVIRONMENTAL CHALLENGES

2.4

Aviation Alternative Fuels Development and Deployment

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2.4.1 INTRODUCTION

2.4.1.1 Background

The commercial aviation enterprise, propelled by a combination of concerns over the long-term use of petroleum-based jet fuel, and consistent with its commitments[1], continues to pursue the utilization of jet fuel produced from alternative sources of hydrocarbons to petroleum. The concerns include supply and price stability, supply security, and environmental impact, all of which might be addressed by the widescale deployment of alternative jet fuel production. However, the environmental concerns, primarily abating future growth of GHG and local air quality emissions, have focused the industry's efforts on the commercialization of low-net-carbon fuels. These fuels, primarily derived from biologically created or waste-stream hydrocarbons, are referred to as renewable jet fuel (RJF) in the remainder of this chapter. Further, since the above concerns are also shared by the U.S. military and the business aviation sectors, the entire jet-powered aviation community is now aligned in their pursuits of RJF commercialization.

As might be expected with the introduction of any new or derivative industrial segment, the widescale development of RJF faces challenges across the breadth of the envisioned supply chain. Although the challenges are many, and sometimes complex, they are being addressed through the focused and aligned efforts of multiple entities and activities around the world. Participants include

- Aircraft operators (commercial, military, and business; i.e., the fuel purchasers);
- Airports, state and local authorities, economic development authorities;
- Airline equipment manufacturers, laboratories, and certification agencies;
- Federal government agencies;
- Fuel producers;
- Supply chain participants;
- Environmental groups;
- Working groups of the above [e.g., Commercial Aviation Alternative Fuels Initiative (CAAFI), Sustainable Aviation Fuel Users Group, Brazilian Alliance for Aviation Biofuels, Aviation Initiative for Renewable Energy in Germany, Australian Initiative for Sustainable Aviation Fuels]; and
- Working group projects and initiatives (e.g., Sustainable Aviation Fuels Northwest, Midwest Aviation Sustainable Biofuels Initiative, Sustainable Aviation Biofuels for Brazil, Farm-to-Fly, and Farm-to-Fly 2.0).

Based on the work of the above entities and initiatives, RJF production efforts have continued to develop. Over the past few years, ASTM International, with the consensus of the industry, has developed a methodology (ASTM D4054) to create and add appropriate RJF production pathways for use as drop-in replacements for jet fuel (ASTM D7566). In 2009, the first ASTM approval of alternative jet fuels covered both fossil fuel-based and biomass-based fuels produced through the Fischer-Tropsch process. In 2011, a key milestone was achieved when ASTM International approved a specification for a 50/50 blend of RJF from a production pathway that converts triacylglycerides from plant oils and animal processing waste [hydroprocessed esters and fatty acids (HEFA)], making this the first ASTM approval of an RJF-specific pathway. The importance of these certifications are that they open the door for commercialization and industrial-scale adoption of other drop-in alternative jet fuels from non-fossil hydrocarbons that are completely compatible with the existing aircraft and engines and fuel handling and storage infrastructure. Immediately following the approval of the HEFA pathway, Lufthansa commenced commercial-proving use of HEFA fuels on more than 1,100 flights between Hamburg and Frankfurt, Germany. The industry is now focused on scaling the HEFA supply chain to enable greater levels of production at reduced cost, with a focus on feedstocks with enhanced sustainability.

At present within ASTM International deliberations, an additional five production pathways are currently being reviewed for qualification. If these efforts prove successful as expected, the industry will have the option to produce RJF from a very broad range of feedstocks and waste streams, using a broad range of technologies—potentially enabling significant levels of fuel production in the near to midterm. Aviation continues to be both feedstock and conversion-process neutral, as there is a good chance that most, if not all, of the approaches being considered will eventually find a local “synergistic home” somewhere in the world, predicated on local socioeconomic, geopolitical, and techno-agronomic conditions, coupled with strategic investments on the part of local entities. The inherently international nature of aviation requires that fuels from around the world be cross-compatible and meet accepted criteria for fuel performance and materials compatibility.

2.4.1.2 Looking Forward

The next major milestone for this nascent industry is to reach commercial-scale production targets of sustainable fuels at reasonable cost and to enable the aviation community to more readily achieve their environmental goals. For example, the FAA has an aspirational goal of 1 billion gallons of RJF usage per year by 2018.[2] In order to reach this ambitious goal, the entire aviation supply chain, including airlines, airports, manufacturers, fuel producers and well over a dozen government agencies coordinated through the FAA Office of Environment and Energy are working through the CAAFI in a concentrated effort to identify the major challenges and determine strategies to facilitate commercial-scale deployment of alternative fuel production. CAAFI and its individual stakeholders have also established strategic alliances and collaborations with strategic partners such as the U.S. DOD and stakeholders in other countries to form a coordinated front.

This section highlights the issues that have been addressed to date and those that remain, including the challenges that still must be overcome to ensure future successes. While this section provides a detailed overview of the subject, it is recommended that readers consult the CAAFI website[3] for both details on the definition of terms and the most recent progress and challenges in this rapidly emerging field.

2.4.2 MOTIVATION FOR THE USE OF RENEWABLE JET FUEL

The commercial aviation industry is interested in fostering the development and deployment of alternative fuels for the following reasons:

- **Supply diversification.** As competition for petroleum-based products intensifies due to increased demand from other industry sectors across the globe and the possible scarcity of this nonrenewable resource in future decades, there are concerns that aviation may find it difficult to economically meet its energy needs over time. The high and volatile price of petroleum-derived jet fuel poses key business challenges to airlines, especially because fuel is the industry's single-highest operating cost, averaging some 35% in 2012. Alternative fuels offer an opportunity to diversify away from petroleum-based jet fuel and reinvent aspects of the fuel supply chain.
- **Operational reliability.** RJF production can bolster the supply of liquid fuel to the aviation industry. Furthermore, RJF production facilities need not be located in the same places where conventional refineries are located. This would allow the geographic diversification of production away from sites prone to natural disasters, such as the Gulf Coast or West Coast.
- **Regional economic expansion.** Production of alternative jet fuels has the potential to generate new jobs and spur economic activity, especially in rural areas where RJF feedstocks can be cultivated. In addition, the growth of a domestic alternative fuels industry would help reduce U.S. imports of foreign crude oil and refined products, freeing up resources to be invested domestically. Alternative jet fuels could reduce or even obviate the need for carbon taxes and emissions trading schemes under consideration for conventional jet fuel that can have antigrowth consequences.
- **Environmental benefit.** Given current technology, there are no practical options to power aircraft engines other than with liquid hydrocarbon fuels. RJF holds great potential to reduce the impact of aircraft operations on air quality and to reduce aviation-related GHG

emissions on a life-cycle basis, thereby advancing the industry's commitment to minimize environmental impact.

In order to be acceptable for use in commercial aircraft, alternative fuels must meet a series of requirements that have been identified though discussions and interactions among all the participants in the jet fuel supply chain. Even though aircraft operators are the end users that will be purchasing and consuming the alternative fuels, successful commercialization of these fuels will occur when every member in the supply chain from the feedstock producer to the airport fuel farm operator has a viable business proposition with respect to alternative fuels. To ensure this success, the following requirements for aviation alternative fuels have been identified:

- **Fuel certification.** Compliance with the relevant ASTM International (or equivalent) certification.
- **Drop-in**. Compatibility with existing storage and handling infrastructure and existing engine, aircraft, and other equipment.
- **Reliability of supply and on-time delivery.** Aircraft operators put special emphasis on the reliability of supply and on-time, on-specification delivery of the fuel; any supplier of jet fuel to the airlines or the military, be it conventional or alternative, must meet the stringent requirements for delivery and availability of the product that airlines and the military require to be able to operate their flights on a daily, year-round basis.
- **Environmental benefit and sustainability.** A reduced environmental footprint relative to traditional jet fuel, with a particular interest in reducing life-cycle GHG emissions and emissions that impact air quality.
- **Economic viability.** The business proposition with respect to alternative fuels has to ensure that the entire supply chain is profitable in order for the industry to grow and mature.

It is also important to remember that aviation is in a unique position with respect to alternative fuels compared to other transportation modes. On the one hand, because airplanes require a fuel that must meet a variety of requirements to ensure safe use, including a high energy density, it is expected that aircraft will continue to use liquid hydrocarbon fuels for the foreseeable future. Alternative fuels such as liquefied hydrogen, liquefied natural gas, or batteries, which are viable for surface transportation applications, are not currently suitable for use on large transport aircraft. Therefore, the quest for alternative jet fuels is focused on drop-in replacements to conventional jet fuel. On the other hand, demand for aviation fuels in the United States is highly concentrated with a few dozen airports representing more than half of the total consumed. Thus, air transportation offers highly concentrated demand that could help in lowering distribution and logistics cost. In addition, the aviation community offers a coordinated sector across airlines, airports, and original equipment manufacturers that is highly motivated to help the alternative fuels industry reach commercial scale.

2.4.3 CURRENT STATE

2.4.3.1 Research and Development

While the RJF industry has been moving forward at a rapid pace, there are critical challenges facing the industry across the supply chain that need to be addressed in order to move the industry forward. CAAFI has worked closely with stakeholders across the alternative jet fuel sector to identify some of the key remaining research and development (R&D) challenges. In particular, flexibility of supply chains, processes, and modeling approaches has been a theme of these discussions. Some of the broad areas that have been identified as needing near-term investment include:

- Modeling approaches that can handle variable supply chain structures, activities, and facilities;
- Systems for modeling and predicting fuel characteristics, and performance;
- Scalable, reliable, resilient, and sustainable feedstocks;
- Cross-cutting technologies that address similar challenges across multiple processing options; and
- Technological or research advances that address cost of final fuel.

These issues speak to two key needs within the alternative jet fuel community: the need for efficient, cost-effective testing of fuels leading toward qualification, and the need for robust, resilient supply chains that are efficient and can supply fuel under a variety of conditions. These are the near-term key issues, but some of the longer-term needs point to the use of nonbiologically based feedstocks such as atmospheric CO_2 or waste that may require further technological development to become technically viable, followed by efforts to ensure economic viability. The Commercial Aviation Alternative Fuels Initiative Research and Development (CAAFI R&D) Team has developed both a position paper and a series of white papers expanding on these challenges.[4]

2.4.3.2 Certification and Qualification

The aviation fuel community has continued its progress towards deployment of RJF. Most noteworthy was the July 2011 approval of a new annex for aviation’s drop-in fuel specification, ASTM International D7566.[5] This new annex adds HEFA fuels as an approved blending component for jet fuel. All commercial airliners and other civil aircraft are now approved to use jet fuel containing up to 50% of this HEFA blending component. HEFA, formerly referred to as hydroprocessed renewable jet (HRJ) fuel, is produced from plant oils or animal fats, and is the first biofuel approved for aviation. The D7566 specification now contains two synthetic blending components for jet fuel: HEFA and FT–synthetic paraffinic kerosene (FT-SPK). Both HEFA and FT-SPK are pure paraffinic fuels that do not contain aromatics, and therefore must be blended with conventional, petroleum-derived jet fuel to meet minimum density and aromatic content requirements.

Several new pathways are currently undergoing evaluation by ASTM International for future incorporation into D7566.

- Hydroprocessed depolymerized cellulosic jet (HDCJ) fuel is produced from cellulosic feedstock (e.g., forestry waste) using a catalytically enhanced pyrolysis process. Unlike HEFA and FT-SPK, the HDCJ blending component contains high levels of aromatics and is denser than conventional jet fuel. It must also be blended to meet maximum density and aromatic requirements.
- Alcohol to jet fuel is also under evaluation. This pathway relies on the dehydration of alcohol to olefins, followed by oligomerization and fractionation to produce jet fuel blending components.
- Direct sugar to hydrocarbon is a pathway that utilizes modified yeast to directly produce a long-chain hydrocarbon (rather than ethanol) from a sugar feedstock.
- Catalytic hydrothermolysis (CH) is a second pathway under evaluation that uses plant oils and animal fats as a feedstock. CH uses water as a catalyst to convert these bio-oils to a jet fuel product.

A final process under evaluation is a modification of the FT-SPK process that produces a more balanced jet fuel blending component that contains aromatics.

Laboratory testing of fuel blending components made from all of these processes has been conducted and the data is being compiled in research reports that will be utilized by the membership of the ASTM International aviation fuel subcommittee to evaluate them for compatibility with jet engine operating requirements. In addition, several of these fuel blending components are in process of being tested on jet engines and jet engine rigs for further evaluation. It is anticipated that approval of these pathways should start occurring in 2014 and continue at a regular pace for the next several years.

As it was mentioned in the preceding section, there is the need for an efficient and cost-effective fuel certification process that can accelerate the timescale and reduce the cost associated with certification of RJF pathways. In particular, a reduction in the fuel volumes required for engine testing would help the process.

2.4.3.3 Environment

The aviation community is seeking alternative jet fuels in part to enhance aviation's environmental performance. This interest has primarily been on GHG emissions reductions to assist in meeting the aviation industry's goal of reaching carbon neutral growth from 2020, in concert with ongoing efforts to reduce particulate emissions and reduce impacts on air quality. In addition, the community recognizes the challenges associated with other aspects of sustainability, such as water use and quality, biodiversity issues (including invasive species), and land use changes. Additional details on these areas are outlined below.

1. While there are well-recognized methods for estimating life-cycle GHG emissions and for assessing other relevant sustainability indicators, there is no universal standard for measuring life-cycle GHG emissions or for assessments of other sustainability indicators. Thus, although it is recognized that many of these unique methodologies are based on scientifically supported approaches, the use of these diverse methods can pose a challenge for comparing among fuels and products, and disagreements can arise over the validity of different approaches. Efforts are currently underway to characterize the differences in life-cycle GHG emissions that result from the use of the varied methodologies employed in different countries and regions.

2. For many fuel producers or purchasers, one criterion for purchasing alternative fuels is that they be no worse than standard petroleum-based fuels with regard to life-cycle GHGs or other sustainability indicators. However, this comparison depends on how one defines the baseline standard petroleum fuel, as the GHG footprint and other sustainability indicators of petroleum fuels evolve with time. Therefore, if one would like to know if a given alternative fuel has improved environmental performance (e.g., a lower life-cycle GHG footprint) than petroleum-based fuels, then a baseline year and process needs to be designated, or the interested party needs to be tracking petroleum-fuel sustainability performance over time.

3. While it is understood the combustion of HEFA and FT-SPK fuels results in reduced emissions of soot and sulfur oxides, and potentially nitrogen oxides, additional emissions measurements are needed to understand how subtle variations in fuel composition will affect the production of these emissions throughout the flight envelope as well as their impacts on air quality and climate change.

4. Many environmental sustainability indicators inherently depend on the local environment in which the impacts occur. For example, if two facilities use the same total amount of freshwater for their activities, but one is located in an arid environment with little available water and the other is in a mesic environment with ample freshwater, the impacts will differ. Accounting for these differences will be a challenge when assessing environmental sustainability.

5. The aforementioned challenges are technical in nature and require decisions about methodologies. However, there is also a philosophical challenge related to sustainability evaluations of alternative fuels, which is when one takes into account more than one or a few environmental indicators, it is likely that fuels will exhibit trade-offs among different components of sustainability. As individual environmental sustainability factors are evaluated, they will need to be compared against one another as well as against other factors such as the economic sustainability of the fuel.

The Commercial Aviation Alternative Fuels Initiative (CAAFI) Environment Team is undertaking work to report on accepted methods and address the open issues with life-cycle GHG emissions analysis and assessment of other sustainability indicators for alternative jet fuels. Key issues and guidance are captured in CAAFI Environment Team working documents.[6]

2.4.3.4 Business and Economics

Cost Reduction

Among the principal challenges facing the RJF industry is price competitiveness with respect to conventional jet fuel. There are many efforts underway to reduce costs and improve the economics of production facilities, including capital costs and operating costs (direct and variable) across the entire supply chain. In November 2012, CAAFI, the FAA, and the DOE's Office of Biomass hosted a workshop to discuss the economics of alternative fuel production of interest to aviation.[7] The workshop convened DOE technologists and techno-economic modeling experts, commercial and military jet fuel customers, academics, and other technical experts to talk about production costs (current and estimated "nth plant") for several pathways:

- FT,

- HEFA,
- Thermo-chemical (pyrolysis),
- Biochemical (fermentation, catalytic upgrading of hydrocarbons),
- Algae-based pathways, and
- Gasification.

The group concluded that the effort had clear value in enabling evaluators to compare and contrast different production methodologies, identify target processes or technologies for cost reduction, and to establish priorities for continued research. DOE has demonstrated its ability to perform a similar function with their evaluations of ethanol production over the past several years.

The workshop findings were also presented at the CAAFI R&D meeting in late 2012. At that point, the team also identified several additional pathways that should be included in future work. CAAFI also committed to continuing to work with DOE and the FAA, through its Center of Excellence program, to find ways to collaborate on identifying means to make techno-economic analysis results comparable, interchangeable among users and evaluators, and more capable of targeting cost reductions.

Tools Development

Over the past few years, ACRP has published a number of reports focused on alternative fuels for use on aircraft and in the airport setting. These reports include:

- *ACRP Report 60: Guidelines for Integrating Alternative Jet Fuels into the Airport Setting*. This handbook identifies the major financial, environmental, logistical, and regulatory considerations that must be addressed in order to create successful projects to introduce alternative jet fuel into the airport setting. The handbook considers the entire supply chain from feedstock generation to delivery at the airport.
- *ACRP Report 83: Assessing Opportunities for Alternative Fuel Distribution Programs*. This handbook and associated toolkit build on Report 60 to focus on the airport as a multimodal node of alternative fuels demand. In addition to including alternative jet fuel, this work also considers alternative fuels for surface transportation, such as CNG, biodiesel, ethanol, and electricity.
- *ACRP Web-Only Document 13: Alternative Fuels as a Means to Reduce* $PM_{2.5}$ *Emissions at Airports*. This project focused on understanding the impact that alternative fuels could have on emissions and ambient concentrations of $PM_{2.5}$ at airports.

Flight Campaigns

The feasibility of aviation alternative fuels for use on aircraft has been proven via a number of demonstration flights spanning many commercial and military airframes and aircraft types. In the past few years, there has been an evolution towards demonstrating the commercial viability of alternative fuels on scheduled commercial flights. In 2011, Lufthansa operated 1,187 commercial flights between Frankfurt and Hamburg using a 50/50 blend of conventional and alternative fuel in one engine.[8] The biofuel was produced by Neste Oil from a series of different feedstocks including camelina, jatropha, and animal fats. The airline used an Airbus A321 aircraft and estimated savings of approximately 1,471 tons of CO_2 from using the alternative fuel mixture. Furthermore, extensive evaluation during and after completion of the flight campaign confirmed previous findings and expectations; no abnormal wear or significant differences in the performance of the engine flown with the HEFA fuel compared to operations with conventional jet fuel. From a fuel handling perspective, test results showed no problems in fuel characteristics, including no separation between the alternative fuel and the conventional blend stock and no significant microbial contamination.

In the United States, Alaska Airlines launched a program with 75 commercial passenger flights to test the use of alternative fuels.[9] The flights started in November 2011, consisting of one daily flight between Seattle, Washington, and Washington, D.C., using Boeing 737 aircraft (11 total) and six daily flights between Seattle and Portland, Oregon, operated by Horizon Air, Alaska's sister carrier, using Bombardier Q400 aircraft. The flights used a 20% blend of alternative fuel made by Dynamic Fuels from cooking oil. It is estimated that the 75 flights would lead to a reduction of 134 tons of CO_2 compared to conventional jet fuel.

2.4.3.5 State and Regional Initiatives

As discussed previously, the industry continues to develop the supply-chain building blocks envisioned as enabling eventual wide-scale RJF commercialization. This includes efforts from agronomic research through fueling logistics. However, even if all the building blocks associated with the supply chain were fully matured individually, some additional effort would be required to pull them together into the creation of a new, efficient HRJ industry. Furthermore, the industry expects to continue to achieve cost reductions over time through elements of achieving greater supply-chain synergies, increased scale and learning curve.

As a result, CAAFI foresees the need to develop local initiatives that pull the building blocks together into actual pilot and commercial-scale subprocesses and projects. In this fashion, cost and risk will be lowered for achieving the eventual full-scale commercialization of multiple processes utilizing a broad range of feedstocks. CAAFI is currently working with several stakeholder groups to establish local projects in multiple states, and intends to leverage that learning and success to all states. The projects will utilize resources available from applicable members of the supply chain, as well as public and private entities. In each case, CAAFI intends to use local feedstock concepts to foster the development of supply-chain building blocks and to create success models or templates which can be used to build scale. At some point, sufficient knowledge and experience is expected to be gained to enable a major participant (airline, fuel producer, supply-chain prime) to submit a request for information to interested parties to start to initiate commercial projects.

2.4.4 FUTURE VISION

The goals and future vision of the aviation enterprise with respect to RJF can be summarized by the following:

- Achieving recognition of the critical need for aviation to be a priority for the development, commercialization, and use of renewable transportation fuels.

- Achieving sustainable (environmental, social, and economic) RJF production at petroleum-based price-parity.
- Achieving RJF production of 1 billion gallons (U.S. customary units) before the end of the decade.
- Achieving qualification of numerous RJF production pathways that will enable production from a broad range of locally significant feedstocks worldwide.
- Achieving post 2020 industry growth and production levels that can contribute significantly to achieving the industry's carbon neutral growth 2020 goals.
- Achieving long-term production levels that can contribute significantly to the industry's 2050 goal of 50% reduction in net CO_2 versus 2005 levels.
- Achieving localized production that contributes to supply surety, supply security, and price stability. Where it makes sense, enabling airports and their airline tenants to form the basis for multimodal distribution of transportation fuels and coproducts from RJF production facilities.
- Achieving a long-term policy framework that creates a level playing field for the production of RJF with respect to other transportation fuels, both petroleum based and renewable.

2.4.5 RESEARCH NEEDS

The research needs with respect to RJF as identified by the aviation enterprise can be categorized and summarized as follows:

2.4.5.1 Research and Development

- Modeling approaches that can handle variable supply chain structures, activities, and facilities.
- Systems for modeling and predicting fuel characteristics and performance.
- Scalable, reliable, resilient, and sustainable feedstocks.

2.4.5.2 Certification and Qualification

- Continue ASTM International certification and qualification process for pathways currently being considered for inclusion in the D7566 standard.
- Develop means to accelerate the timescale and reduce the cost associated with certification of RJF pathway.
- Investigate possibilities for reducing fuel volumes required for engine testing.

2.4.5.3 Environment

- Identify technical differences among existing environmental sustainability tools and accounting schemes, while continuing to work to broaden data and analysis availability.
- Establish environmental sustainability indicators for potential evaluation, methodologies for their calculation, and baseline values for comparison.
- Conduct emissions measurements of RJF types as they become available to develop an understanding of how fuel composition is related to emissions production.

- Evaluate environmental sustainability indicators for comparison against the petroleum fuel baseline and other factors such as economic sustainability.

2.4.5.4 Business and Economics

- Continue efforts to reduce costs and improve the economics of production facilities, including capital costs and operating costs.
- Identify means to make techno-economic analysis results comparable, interchangeable among users and evaluators, and more capable of targeting cost reductions.
- Continue developing guidance material and tools to help producers, consumers, and other participants in the supply chain identify and quantify attractive business models.

2.4.5.5 State and Regional Initiatives

- Continue developing local initiatives to pull together the building blocks of RJF production into pilot and commercial-scale subprocesses and projects.
- Develop a process template to facilitate the creation of local initiatives that respond to their particular local conditions, assets, and strengths.

NOTES

1. In 2008, the worldwide aviation industry made a commitment to achieve carbon neutral growth and further reduce carbon emissions beyond that (see Aviation Industry Commitment to Action on Climate Change, signed in 2008). Since then, the industry has undertaken action to meet its commitment while supporting government policies and a global regulatory framework to complement and support industry efforts, as reflected in the industry's 2012 declaration (see http://www.enviro.aero/Aviationindustry environmentaldeclaration.aspx). For further dialogue on the quantitative goals subsequently agreed upon by the IATA and the ICAO, see A Sustainable Flightpath Towards Reducing Emissions, a position paper presented by the global aviation industry at the Doha United Nations Framework Convention on Climate Change Climate Talks in November 2012. Available at http://www.atag.org/component/downloads/downloads/203.html).
2. http://www.faa.gov/about/plans_reports/media/Destination2025.pdf.
3. http://www.caafi.org/.
4. http://www.caafi.org/information/rdchallenges.html.
5. As previously noted, the first ASTM approval of alternative jet fuels in 2009 covered both fossil-fuel–based and biomass-based fuels produced through the FT process.
6. http://www.caafi.org/information/fuelreadinesstools.html.
7. http://www1.eere.energy.gov/biomass/past_meetings.html.
8. http://www.puresky.de/en/.
9. http://www.alaskaair.com/content/about-us/social-responsibility/fly-green/fly-green.aspx.

3

Processes and Tools for Implementing Sustainable Solutions

3 PROCESSES AND TOOLS FOR IMPLEMENTING SUSTAINABLE SOLUTIONS

3.1

Environmental Review Under NEPA

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3.1.1 INTRODUCTION

The environmental review and resource management processes within the aviation system consist primarily of reviews conducted under the National Environmental Policy Act of 1969 (NEPA) and other state and local environmental laws, as well as actions taken to develop and implement environmental management systems (EMS) and sustainability management plans. The following sections discuss the research needs in these areas.

3.1.2 ENVIRONMENTAL REVIEW AND MANAGEMENT

Conducting environmental review under both NEPA and similar state-based reviews can result in a complex, controversial, and often inefficient process. Before the FAA can undertake a federal action, including approval of an airport action, compliance with NEPA is required. Such approvals include, but are not limited to, revisions to the National Airspace System (NAS), approval of airport layout plans and funding for airport improvements, airline operational specifications changes, and amendments to the Part 139 Airport Certification. As a result, the NEPA process may involve stakeholders from the FAA; airport operators, tenants and airlines; other federal, state, and local agencies; tribal organizations; and the general public. Each of these parties experience challenges with the NEPA process, many of which arise because of the amount of time required to complete the process.

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. Airspace changes, airline service, and airport development are guided by, among other things, FAA's orders and advisory circulars (ACs). The environmental review process itself is guided by NEPA and the Council on Environmental Quality (CEQ), and FAA Orders such as 1050.1E, 5050.4B, 7400.2J, and their revisions, as well as by special purpose laws, such as the Clean Water Act, the Clean Air Act, etc. In addition to the federal requirements, there are a variety of state and local laws that may include NEPA-like processes, as well as state-level special purpose laws. As a result, many believe that the cost and time needed to comply with NEPA are unnecessarily burdensome. There seems to be some general concurrence that there are opportunities to improve the process to make it more efficient and achieve the underlying purpose of NEPA.

FAA is currently updating its overarching procedures for implementing NEPA, which are presented in FAA Order 1050.1: Environmental Impacts: Policies and Procedures. During the update of the order, FAA identified several issues that are being addressed through the update, including

- The revision will reorganize and revise the text to make requirements and policy clearer (e.g., using plain language) to reduce redundancies and provide the FAA NEPA practitioner with a more user-friendly order. It also includes updates to reflect FAA's Next Generation Air Transportation System (NextGen) capabilities and terminology. The order includes a desk reference to complement FAA Order 1050.1F and provide explanatory guidance for environmental impact analysis (EIA).
- The FAA is expanding and updating the list of categorical exclusions and actions that typically require environmental assessments (EAs) and environmental impact statements (EISs) to better reflect its past experiences and ensure the appropriate review is being done.
- The updated order will incorporate recommendations and approaches from several guidance documents which have been issued by either FAA or the CEQ over the past few years that help clarify the NEPA process and FAA procedures. For example, FAA issued a guidance memo to focus the assessments in EAs. This issue was not just limited to FAA and as a consequence, CEQ issued similar guidance entitled Improving the Process for Preparing Efficient and Timely Environmental Reviews under NEPA (March 6, 2012).

Airport operators are finding that their internal processes for project planning and development often are not well integrated with the NEPA process requirements. This can lead to environmental considerations not being taken into account up front, resulting in a delay of the project as planners re-evaluate project alternatives. It can also lead to the NEPA analysis being initiated prior to sufficient planning, which could require revisions to analyses and therefore delay the project until requisite project data is available. Protracted environmental documentation can impede development, increase costs, and further polarize the relationship of the airport operator with regulatory agencies and airport neighbors.

Some members of the public believe the NEPA process fails to address important objectives in terms of resource protection and preservation of quality of life. Further, some believe the NEPA process does not necessarily lead to better project decisions and, instead, may simply confirm a choice that had already been made. Public opposition and litigation on environmental grounds add time and increase the uncertainty of the environmental review processes.

Environmental review, management, compliance, rulemaking, and enforcement roles are shared among stakeholders at the federal, state, and local levels. For example, changes in airport operating arrival and departure procedures may originate within the FAA, but could involve airport operators, aircraft operators and tenants, local land use officials, and the general public. Unless ground-based systems are involved, the effects of these actions are principally noise, land use, and air emissions based.

Due to differences in the environmental review process depending on location of the project, coordination efforts could be improved between the FAA and other stakeholders to ensure that the project does not incur an increase in time, cost, and difficulty.

The perception and reality of noise, air pollution, incompatible land development, water quality, traffic congestion, and other environmental effects, along with the level of trust or confidence in analyses of these effects, must be considered when assessing how well environmental review processes are working. These considerations drive political, legal, and other decisions that affect the ability to expand the aviation system in a timely manner. Similarly, decisions regarding aviation have real effects on the environment that may or may not be fully consistent with federal, state, and local goals. Increasingly, airports, airlines, and manufacturers 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.

3.1.3 CURRENT STATE

The aviation industry, government agencies, and Congress have had increased attention on issues at congested airports and inefficient airspace system and flight operations. Over the years, stakeholders have identified the environmental processes (the analyses conducted under NEPA including compliance with special purpose laws) among the causes for delays in implementing safety, capacity, and efficiency initiatives. In response, government and industry entities have increased their 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. However, despite efforts to improve the process, some believe that because few large airport improvement projects have been undertaken in the past 5 years, improvements are untested and unlikely to have taken hold. Therefore, a continued need exists to identify additional improvements to increase the efficiency and reduce the timeline associated with NEPA compliance.

FAA has been focused on implementing streamlining initiatives throughout the last several years particularly with airspace-related federal actions including NextGen (e.g., 1050.1E Guidance Memo #2 on Preparing Focused, Concise, and Timely Environmental Assessments; and the Navigation Procedures Implementation Program,[1] which includes several recommendations on improving the environmental review process for instrument flight procedures). Congress included provisions intended to streamline environmental review for airspace-related projects in the FAA Modernization and Reform Act of 2012, the FAA reauthorization bill for 2011–2014. These provisions included two additional legislative categorical exclusions, amendments to the National Parks Air Tour Program, and added support to the state block grant program and state authority to carry out NEPA in that context. As mentioned earlier, FAA is currently updating FAA Order 1050.1E and creating a complementary desk reference focused on providing explanatory guidance for EIAs. FAA expects to publish the updated order and desk reference in 2014.

In March 2013, CEQ issued two new handbooks that encourage more efficient environmental reviews under NEPA. One is designed to assist with integrating NEPA with the National Historic Preservation Act process and the other with integrating NEPA and the California Environmental Quality Act (CEQA), a state-based NEPA-like law. These two handbooks are designed to promote informed federal decisions on projects and to help agencies improve efficiency, maximize staff resources, and reduce costs.

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 causes of the sometimes lengthy time periods to review and approve airport projects. In meetings of Airports Council International North America (ACI-NA) and the Airport Consultants Council, stakeholders have noted that one of the reasons 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 or environmental requirements. In 2009, *ACRP Synthesis Report 17: Approaches to Integrating Airport Development and Federal Environmental Review Processes* identified contributors to prolonged NEPA processes. One of the areas noted in the synthesis was the effects of disconnects between NEPA and planning. Simultaneously, a group of volunteers from ACI-NA has formed a Planning–NEPA integration task force. In mid-2013, ACI-NA issued a best management practices guide, identifying lessons learned over the last decade. It also recommends actions and issues that should be considered to better integrate project planning and environmental review processes.

Finally, while some projects have benefitted from these lessons learned, in the past 5 years there have been few major airport improvements projects due to national economic conditions. Therefore, it is unclear if there will be meaningful benefits from the lessons learned on past NEPA processing efforts. Because of past experiences, complaints persist that the process takes unnecessary time, is inefficient, and results in unnecessary project costs. FAA has recognized improvements in the preparation and processing of environmental reviews associated with airspace procedures through its Optimization of Airspace Procedures in the Metroplex program. Additionally, based on recent NEPA reviews, FAA has seen its FAA Order 1050.1E Guidance Memo 2: Preparing Focused, Concise, and Timely Environmental Assessments, result in a greater shift towards more concise and focused EA documents. Other stakeholders are not convinced that any meaningful improvements have resulted. A better understanding of the actual effects of recent initiatives and problems associated with integrating project development and environmental reviews will be important in developing new and more-efficient decision making.

3.1.4 FUTURE VISION

Reducing the amount of time needed to comply with NEPA while maintaining stakeholder acceptance and legal compliance for FAA actions will require

- Improved analytic tools;
- Improved processes to integrate planning and environmental reviews;
- Improved guidance for consideration of special purpose laws in FAA NEPA documents;
- Improved ways to ensure sufficient planning and other needed data are available for the follow-on EAs;

- Using sustainability initiatives and measures to reduce a project's environmental effects and provide or enhance its social and economic benefits;
- Ensure greater consistency and predictability in the application of NEPA;
- Improved coordination with state review processes and permitting processes with other federal agencies;
- 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;
- Improved collaboration and coordination among key stakeholders, both at the tactical (i.e., project) and strategic level; and
- Use of communication technologies to enhance the transparency and public understanding of a proposed project, its alternatives, and its environmental effects.

Environmental review, management, and compliance processes should, among other things,

- Inform decision makers and the public of the environmental impacts of projects.
- Document in plain language and be clear, concise, and to the point so the public can readily understand the analysis. The documentation should be transparent in its use of data, consideration of alternatives and analysis results, and meet the requirements of FAA's orders.
- Support selection and implementation of projects that promote transportation and sustainability (i.e., environmental, social, and economic) goals.
- Ensure compliance with environmental requirements.
- Ensure transparency and accountability within and outside an organization for environmental requirements or goals.
- Encourage and facilitate coordination among stakeholders.
- Work within reasonable and predictable timeframes.
- Minimize costs.

3.1.5 RESEARCH NEEDS

Objective and empirical research regarding the effectiveness, efficiency, accuracy, and shortcomings of environmental processes as applied in the airspace–airport setting, as well as potential means to improve these processes, would be useful to policy makers in evaluating whether existing processes should be changed and, if needed, in what manner. Many of 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.

Identifying ways the FAA, airport operators, airlines, and consultants can better integrate project planning with the needs of the environmental review process is a key objective. 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 should

- Evaluate the adequacy of current environmental review and management tools for addressing environmental challenges, such as climate change, quality of life, and water quality.

- Identify the time and cost of the environmental review and compliance processes currently required for various actions or projects and determine if and why such timelines and costs vary by project type, regional location, and impacts.
- Identify if there are differences in how NEPA is implemented among federal agencies and reasons for those differences.
- Identify where additional guidance and best practices could be prepared that would improve the efficiency and document quality.
- Identify the probable causes of time delays in decision making, including:
  - Disputes about purpose and need,
  - Disputes about alternatives,
  - Multiagency and stakeholder coordination issues,
  - Why environmental impact issues can be difficult to solve,
  - Issues related to developing mutually acceptable mitigation, and
  - Efficiently addressing community opposition and highly controversial issues.
- Identify why and how project revisions occur.
- Identify how staffing availability or resource availability affects timelines and costs.
- Locate critical bottlenecks in the review process and developing possible solutions that would still meet process and substantive goals.
- Assess the effects of current and forthcoming streamlining and other process measures, as well as the effects of implementing new regulations or guidance to make the review process more efficient
- Develop approaches for conveying aviation-related environmental information to the public in brief, understandable, and meaningful ways.
- Consider the potential relationships between environmental management or sustainability management systems and traditional environmental review processes.
- Determine the best ways of developing and integrating forecasts into the environmental review process and strategies that could be deployed in cases where the forecasts are likely to change over time, requiring later additional environmental review.
- Review the adequacy of mitigation tools available to address community concerns and opposition, as well as the effects of mitigation on the decision-making process (an effort that links with the research needs listed in the noise, air quality, water quality, and tool suite chapters).
- Analyze the factors critical to addressing community opposition and concerns.
- Evaluate the effectiveness of components of the environmental review process and developing measures to benchmark best practices.

NOTE

1. http://www.faa.gov/nextgen/media/NAV%20Lean%20Final%20Report.pdf.

3 PROCESSES AND TOOLS FOR IMPLEMENTING SUSTAINABLE SOLUTIONS

3.2

Environmental Management Systems and Sustainability Measurement

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3.2.1 INTRODUCTION

An EMS is a structure that organizes and ensures that an organization proactively and systematically manages its operations that have potential environmental effects and its regulatory compliance obligations. Further, EMS is a tool to integrate environmental protection objectives into the core business and operational strategies of an organization. EMSs have been widely adopted internationally by industry and government, and have been effective at improving organizational regulatory compliance, environmental performance, and supporting mitigation monitoring.

EMSs are increasingly being used in the aviation industry to manage environmental issues. Such systems are intended to methodically assure environmental goals and requirements are brought into organizational decision making from top to bottom and to continually manage environmental issues through a cycle of planning, implementation, data collection, and review for changes, a process known as Plan, Do, Check, Act. Some airports rely on the international standard ISO 14001: Environmental Management System—Requirements and Guidance for Use in structuring and defining their EMSs. Some have also secured third-party certification to the ISO 14001 Standard for all or part of their facilities.

3.2.2 CURRENT STATE

Any organization in any sector can implement an EMS. In 2007, President George W. Bush issued Executive Order (EO) 13423: Strengthening Federal Environmental, Energy and

Transportation, which required all federal agencies to establish an EMS as the framework to manage and continually improve sustainability practices. In October 2009, President Obama issued EO 13514: Federal Leadership in Environmental, Energy and Economic Performance, reiterating the EMS requirement.

These EOs and U.S. Department of Transportation (DOT) Order 5641.1A: DOT Internal Environmental Management Systems require all appropriate organizational levels in federal agencies to implement EMSs to ensure the use of the EMS as the primary management approach for addressing environmental aspects of internal agency operations and activities. In response, all federal agencies, including the FAA, have implemented EMSs. To meet these requirements, FAA created an internal higher tier EMS and organizational-level EMSs and has integrated relevant environmental objectives into the EMS. To promote airport EMSs, FAA grants funds toward the development of EMSs at large and medium hub airports.

ISO 14001: Environmental Management System—Requirements and Guidance for Use is the best-known model for an EMS and is generally considered a best practice. Organizations that implement an EMS consistent with the ISO 14001 Standard can choose to be audited and certified by an independent accredited certification body or registrar. The U.S. Environmental Protection Agency (EPA) has developed a basic EMS structure that focuses primarily on setting objectives and targets, development of the programs to achieve them, and monitoring of the programs' effectiveness. EPA also recognizes ISO 14001 as a standard that meets its definitions of an EMS. No third-party certification is included as a requirement of the EPA.[1]

The FAA issued an agencywide requirement, Order 1050.21, for the development of an EMS at all of its operations. To support this directive, the FAA developed guidance—Key Elements of an EMS—that identifies elements that it expects for FAA operations. The guidance closely follows the elements included in the ISO 14001 Standard but does not include some of the specific requirements. For example, the FAA does not include third-party certification as a requirement. In 2007 the FAA issued AC No. 150/5050-8, which provided guidance to airport sponsors using federal money on developing EMSs. It identifies that airport sponsors must use an existing standard and references the EPA and ISO 14001 Standards, specifically.

The Eco-Management and Audit Scheme (EMAS) standard is another EMS standard that is broadly used in Europe. It was developed by the European Commission in 1995 and has a heavy focus on monitoring and reporting of environmental performance. EMAS includes a third-party registration scheme similar to ISO 14001. Originally open to organizations with operations in European Union countries, registration has been opened to all organizations regardless of location within the past 2 years. EMAS registrations are reported at over 8,000 by the end of 2011.[2]

FAA is in the process of developing a strategic EMS for NextGen (NextGen EMS). The ability to overcome critical environmental challenges is dependent on achieving the NextGen goal of increasing NAS capacity and efficiency to meet projected growth in the demand for air transportation, as well as goals for each of the five environmental aspects of focus (aircraft noise, air quality, global climate effects, energy, and water quality). The range of environmental issues, interdependencies, and stakeholders present an extremely complex management paradigm. This requires system-level coordination, tracking, and goal setting, as well as action from individual organizations to achieve NextGen goals. To address this need, FAA and other stakeholders currently are working to make the EMS a guiding concept for NextGen through the development of the NextGen EMS framework, which will complement stakeholder-level EMSs by offering connections to their ongoing activities while keeping a strategic focus. NextGen EMS' flexible framework necessary to manage and assess the many complex, interrelated, and evolving environmental issues associated with significant aviation growth. FAA is in the process of developing this framework in collaboration with stakeholders.

ACRP Synthesis Report 44: Environmental Management System Development Process was published in April 2013 and synthesizes the current practice of EMS development throughout the United States and Canada. The report surveyed airports and provides guidance to airports with regard to current state of practice in the airport industry and answers questions that airport managers and personnel responsible for environmental management at airports may have on what their peers are doing. Among the conclusions are the following.

- Airports found that an EMS is an effective and useful way to improve environmental performance and increase operating efficiency. A system built with the proper structure, resources, and processes will result in improved performance.
- The ISO 14001 Standard is the dominant framework used by the surveyed airports to develop their EMS, although selecting ISO 14001 does not necessarily mean that third-party verification and certification is being pursued within their EMS.
- Airports that chose not to seek certification cited the cost and time required.
- Airports that chose certification perceive value in terms of independent confirmation of their EMS and credibility.
- Airports that reported not using the ISO 14001 Standard as the basis for their EMS still address a great deal of the content of ISO 14001.
- Airports achieved the benefits that had initially motivated them to implement an EMS.
- Improved environmental performance and improved employee understanding of environmental issues and responsibilities were the highest ranked reasons for developing an EMS.
- Airports that have a primary focus on compliance include typical concerns such as stormwater, spill avoidance, and air emissions.
- Most airports expanded their EMS beyond compliance to address sustainability such as greenhouse gas (GHG) emissions, green building, and green purchasing.
- An EMS can be scaled to meet any individual airport's requirements and can become more ambitious over time.
- Many of the airports reported that they plan to expand the scope of their EMS over the next 5 years.
- Using a crossfunctional team may be a critical first step in developing an EMS that more fully integrates into airport operations and thus provides greater benefits.
- The greatest barrier to success in implementing an EMS was competing resources, followed by insufficient staff and operations management resistance.

3.2.3 FUTURE VISION

The benefits of EMS are clearly documented throughout literature, organization experience, as well as on EPA's website.[3] However, aviation industry participation in EMS is far from widespread. Additional research into the benefits of EMS for compliance, strategic, and mitigation monitoring may encourage additional organizations to implement an EMS. The future vision is for widespread adoption of EMS in the aviation industry being used not only for compliance, but also strategic planning and mitigation monitoring purposes.

3.2.4 RESEARCH NEEDS

The recently published ACRP study and associated case studies provides indications of what contributes to a successful EMS, and it was clear most airports achieved their intentions. However, a research gap appears to exist that could be filled by investigating organizational issues associated with EMS implementation. For instance, in some cases there was inconsistency in the broad-based involvement by airport staff to develop the EMS versus the staff responsible for maintaining the EMS. Research is needed concerning the need to coordinate the implementation of EMS airportwide (among tenants and airport operators) relative to achieving the goals of the EMS.

The large differences in the costs reported to implement an EMS were unexpected in the ACRP Synthesis Report. It was suggested a better understanding of the costs is needed. The synthesis found that costs ranged from $60,000 to $11 million. The staff hours ranged from 0 to 45,000 h at large hub airports, again a range making it difficult to determine reasonable costs. Without further study, cost comparisons among the airports surveyed cannot be made.

Further research related to EMS is needed in the following areas:

- Guidance on how to successfully structure, implement, and improve an EMS.
- Guidance to assist airports in integrating sustainability and EMS.
- Costs to develop, implement, and manage EMS at airports.
- Evaluating the adequacy of EMS approaches for addressing new environmental challenges such as climate change.
- Developing approaches for conveying aviation-related environmental information in brief, understandable, and meaningful ways.
- Considering the potential relationships between environmental management or sustainability management systems and traditional environmental review processes.
- Evaluating the use of EMS for mitigation monitoring and the use of that information to determine the effectiveness of the monitored mitigation for use in future airport projects.
- Evaluating the use of EMS for strategically managing local and regional aviation environmental issues.

3.2.5 ADDITIONAL RESOURCES

ACRP Synthesis Report 17: Approaches to Integrating Airport Development and Federal Environmental Review Processes. Transportation Research Board of the National Academies, Washington, D.C., 2009. Available at http://onlinepubs.trb.org/onlinepubs/acrp/acrp_syn_017.pdf.

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NOTES

1. http://www.epa.gov/ems/.
2. http://ec.europa.eu/environment/emas/.
3. http://www.epa.gov/ems/.

3 PROCESSES AND TOOLS FOR IMPLEMENTING SUSTAINABLE SOLUTIONS

3.3

Aviation Environmental Modeling Tool Suite

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3.3.1 INTRODUCTION

Although aviation has made major strides in lessening the environmental effects of aviation over the past several decades, noise and emissions[1] continue to have an impact on civil aviation's capacity to grow and to operate. Although there are multiple byproducts and interdependences that are important to understand, aircraft noise, emissions, and fuel burn are particularly important. Technologically and economically feasible measures are needed to decrease noise, emissions, and fuel burn. Substantial progress already has been made, but additional progress is needed from aircraft and engine source reduction technologies, alternative fuels, operational procedures, air traffic management modernization, and policy measures. The challenge is to understand the interdependencies among aircraft noise, emissions, and energy use, including among emissions of various air pollutants, to develop appropriate mitigation strategies and ultimately minimize environmental impacts as a whole. It also is critical to employ robust cost–benefit analyses to inform decision-making processes, ensuring policymakers have a complete set of information.

The FAA, in collaboration with the National Aeronautics and Space Administration (NASA) and Transport Canada, are well into a multiyear effort to develop an integrated tool suite that can assess environmental impacts, trade-offs, interrelationships, and economic consequences in an interdisciplinary fashion.[2] The long-term aim is to provide a seamless, comprehensive set of tools to address all aspects of aviation noise and emissions. These tools provide decision makers—including the aviation industry, government, and the public—the information needed to develop responsive strategies: cost-effective strategies driven by benefits that enable environmentally responsible aviation growth. The aviation industry needs to analyze the interdependencies amongst noise, emissions, and energy use in both the design and operational contexts. Government agencies need to assess the environmental consequences of proposed regulatory actions and policy decisions in terms of noise and emissions, 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 takes time to develop interdisciplinary decision support tools. Meanwhile, it is important to maintain a state-of-the-art analytical capability to support ongoing needs for aviation noise and emissions analysis.

3.3.2 CURRENT STATE

The FAA has long 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)[3] for singular airport analyses, the Noise Integrated Routing System (NIRS)[4] for regional noise assessment, and the Emissions and Dispersion Modeling System (EDMS)[5] for airport emissions capabilities. FAA has also developed the Model for Assessing Global Exposure to Noise from Transport Aircraft (MAGENTA)[6] for national and global noise assessments, and the System for Assessing Aviation's Global Emissions (SAGE)[7], which estimates aircraft fuel burn and emissions over the entire international and domestic flight regime.

These legacy tools, like many efforts to address aircraft noise and aviation air pollutant emissions issues, have historically been advanced along independent paths, with separate foci and modeling approaches. The result was that research projects, analyses, metrics, and decisions were not accounting for interdependencies among noise, emissions, and fuel burn. To better account for interdependencies, the FAA has developed the Aviation Environmental Design Tool (AEDT)[8] as a replacement for the legacy tools, INM, NIRS, EDMS, SAGE, and MAGENTA. AEDT is a software system that models aircraft performance in space and time to quantify fuel consumption, emissions, and noise. It takes detailed fleet descriptions and flight schedules as input and produces estimates of noise, fuel burn, and emissions inventories at global, regional, and local levels. By leveraging the knowledge FAA has gained from creating and using current and legacy environmental tools, AEDT is the next-generation FAA environmental consequence tool satisfying the need to consider the interdependencies between aircraft-related fuel burn, emissions, and noise.

AEDT is being released publicly in two phases. The first phase, AEDT 2a, is used for air traffic airspace and procedure actions where the study area is larger than the immediate vicinity of the airport, incorporates more than one airport, or includes actions above 3,000 ft above ground level.[9] AEDT 2a replaces NIRS, FAA's current analysis tool for these applicable analyses, and is able to perform environmental analysis for airspace actions to comply with NEPA requirements. The second phase, AEDT 2b, will replace the current public-use aviation air quality and noise analysis tools EDMS and INM.

As is shown in Figure 1, AEDT is at the core of the analytical tools suite being developed to examine the environmental impacts of aviation. This tool suite comprises aircraft design, alternative fuels, AEDT, and the Aviation Environmental Portfolio Management Tool (APMT), which includes both economic and EIA capabilities.[10] The APMT economic model takes inputs from different policy and market scenarios, as well as existing and potential new aircraft types [the latter from environmental design space (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.

The aviation environmental tool suite contains predictive capabilities for noise and emissions from aircraft by leveraging the knowledge that NASA has developed in aircraft and engine design and analyses models. These models include aircraft noise prediction, advanced vehicle performance analysis, and engine performance and mechanical design tools. The EDS[11] leverages the NASA legacy aircraft design tools to estimate aircraft performance and environmental trade-offs for different technology assumptions and policy scenarios. In addition to EDS, the FAA has been using a variety of tools in their analyses, including the Transport Aircraft System OPTimization, Program for Aircraft Synthesis Studies, and Piano.[12]

To complement the predictive capabilities for aircraft and engine design, elements will be added to the aviation environmental tool suite to evaluate alternative jet fuels. Much of this capability is coming from ongoing research within the Partnership for AiR Transportation Noise and Emissions Reduction Center of Excellence to measure the emissions from alternative jet fuel combustion[13] and to evaluate the life-cycle GHG emissions from alternative jet fuel use.[14] Some of these data have already been included in the Argonne National Laboratories Greenhouse Gases, Regulatory Emissions, and Energy Use in Transportation (GREET) model.[15]

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; comparison 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 system-level assessment. The uncertainty analysis uses total sensitivity indices to rank the inputs by relative cause of output uncertainty. The uncertainty quantification for AEDT 2a can be found online. Future versions of AEDT will be examined a similar way.

This integrated tool suite has been used to characterize and quantify 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. For example, during the 8th and 9th meetings of the International Civil Aviation Organization Committee on Aviation Environmental Protection, which took place in 2010 and 2013, respectively, AEDT and APMT were used to inform the U.S. positions on the internationally negotiated oxides of nitrogen and noise stringencies, respectively.

3.3.3 FUTURE VISION

The integrated environmental tool suite is being used by the FAA to provide data to inform its environmental policy making (Figure 1). This is a result of the FAA, in collaboration with NASA and Transport Canada, conducting a multiyear effort to develop a robust, comprehensive framework of aviation environmental analytical tools and methodologies that enable more informed federal policy and budgetary decision making, as well as facilitate international agreements on standards, recommendation practices, and mitigation options. The components of the tool suite will continue to need improvements; there is also a continued need to improve coordination and data hand-offs among the tools such that the suite reaches its potential to effectively assess and communicate environmental effects, trade-offs, interrelationships, and economic consequences. The long-term aim is to provide a seamless, comprehensive set of tools to address all aspects of aviation noise, fuel burn, and emissions. This approach should be made as affordable as it is effective and informative.

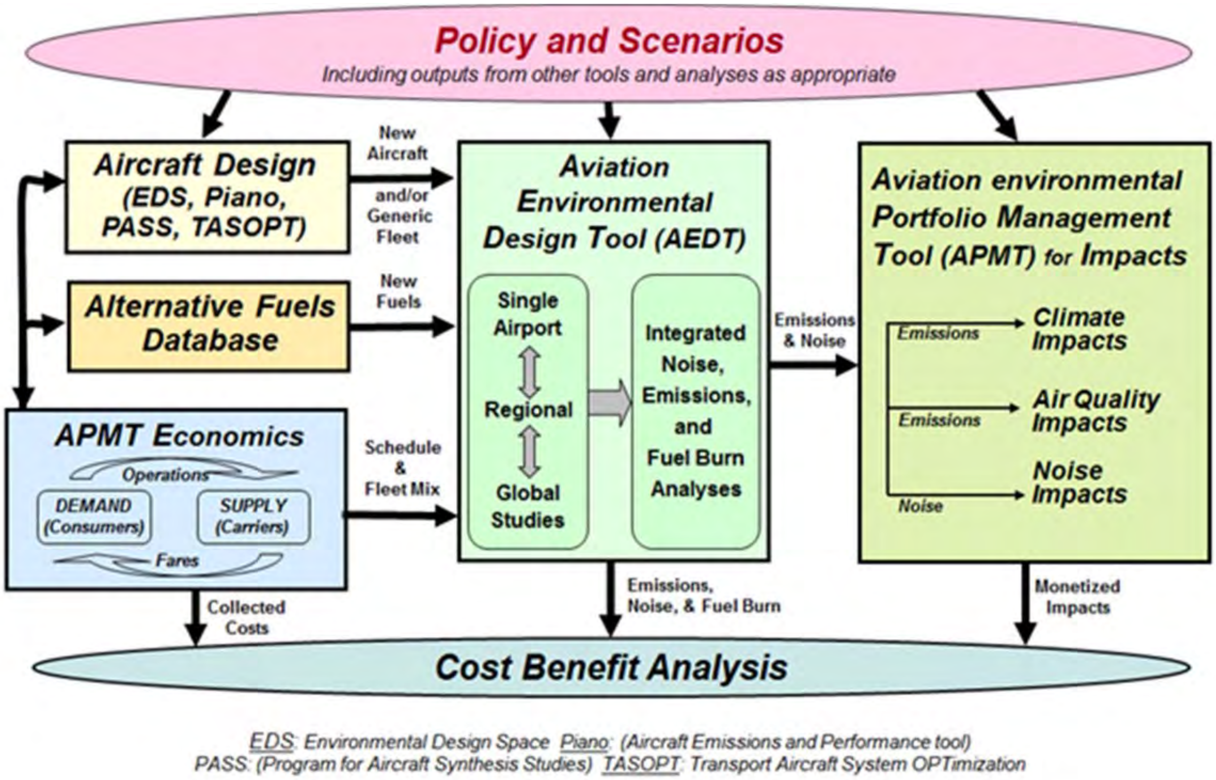

FIGURE 1 Schematic of the FAA Office of Environment and Energy's integrated tools suite currently under development, consisting of the EDS, APMT, and AEDT.

3.3.4 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 for the assessment of aircraft noise exposure and impacts, as well as aviation pollutant emissions and their impacts on air quality and climate change. Specific research needs involving aviation environmental tools include the following.

- For aircraft design, development is needed of appropriate models to represent fuel burn, noise, and emissions from current and future aircraft and ensure the aviation environmental tools suite can leverage outputs from varied aircraft performance tools.
- For alternative fuels, databases of and algorithms need to be developed that can use information on life-cycle GHG emissions and the change in pollutant emissions that accompanies the use of drop-in alternative jet fuels.
- For APMT, capabilities to examine varied pollutant scales from local to global need to be incorporated and integrated into research advances on new environmental impact metrics, econometrics modules, and socioeconomic data.
- For AEDT, the ability to use high-fidelity meteorological data for aircraft performance needs to be included along with acoustic propagation and pollutant dispersion; improvement of predictions of en-route noise, noise propagation, and ground absorption; taxi noise; and incorporation of Base of Aircraft Data 4[16] for aircraft performance.

- The quantitative assessment of the tool suite needs to be advanced at both the individual tool and system level, and uncertainty quantification to provide guidance on the level of confidence that can be placed on tool outputs needs to be continued and encouragement of international acceptance.

FAA is pursuing development of the aviation environmental tool suite with intended uses ranging from aircraft design and technology impact studies, to airport improvement projects, as well as noise and emissions certification standards rule making.

NOTES

1. Throughout this discussion the term "emissions" refers to air pollutants.
2. http://www.faa.gov/about/office_org/headquarters_offices/apl/research/models/.
3. For more on INM, see http://www.faa.gov/about/office_org/headquarters_offices/apl/research/models/inm_model/.
4. For more on NIRS, see http://www.faa.gov/about/office_org/headquarters_offices/apl/research/models/nirs_nst/.
5. For more on EDMS, see http://www.faa.gov/about/office_org/headquarters_offices/apl/research/models/edms_model/.
6. For more on MAGENTA, see http://www.faa.gov/about/office_org/headquarters_offices/apl/research/models/magenta/.
7. For more on SAGE, see http://www.faa.gov/about/office_org/headquarters_offices/apl/research/models/sage/.
8. For more on AEDT, as well as information on how to obtain the software and to access information such as the user's guide, see https://aedt.faa.gov/.
9. These types of analyses will be referred to as applicable analyses throughout this chapter.
10. For more on APMT, see http://www.faa.gov/about/office_org/headquarters_offices/apl/research/models/apmt/ and http://web.mit.edu/aeroastro/partner/apmt/index.html.
11. For more information, see http://partner.mit.edu/projects/environmental-design-space and http://www.faa.gov/about/office_org/headquarters_offices/apl/research/models/eds/.
12. For example, see http://partner.mit.edu/projects/metrics-aviation-co2-standard and http://partner.mit.edu/projects/analysis-missions-specifications.
13. For more information, see http://partner.mit.edu/projects/emissions-characteristics-alternative-aviation-fuels.
14. For more information, see http://partner.mit.edu/projects/alternative-jet-fuel-sustainability and http://partner.mit.edu/projects/environmental-cost-benefit-analysis-alternative-jet-fuels.
15. For information on the GREET model, visit http://greet.es.anl.gov/ and for supporting information on the aviation components, see http://greet.es.anl.gov/publication-aviation-lca.
16. http://www.eurocontrol.int/services/bada.

3 PROCESSES AND TOOLS FOR IMPLEMENTING SUSTAINABLE SOLUTIONS

3.4

Public Health in Aviation

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3.4.1 INTRODUCTION

The public health aspects of airports, and all large public facilities for that matter, have been traditionally regulated by local public health agencies and laws which govern such activities as food safety in commercial kitchens, indoor air and water quality, asbestos and lead exposures, and the like. In recent years, with the rise of obesity, diabetes, and other lifestyle-associated diseases in the population, there has been a new focus on the impacts of airport development on public health, in areas such as walkability, access to healthy food, natural light, and contingency planning for the spread of infectious diseases.

Public health started out with a focus on large-scale issues that have the potential to impact many people, such as food and water sanitation. Over time public health work has grown to include much more than infectious disease containment and prevention. Attention is increasingly being paid to overall physical health, occupational health and safety, mental health and well-being, and community livability as contributors to public health. This chapter discusses the current state and future vision of the impacts of aviation on public health, and identifies some topics where additional research is needed. A list of references is provided at the end for exploring this topic further.

3.4.2 CURRENT STATE

The impacts of aviation on public health range from the contributions of toxins and pathogens on specific illnesses to the more general role aviation plays in the well-being and livability of geographic areas. In general, the former tend to be fairly well understood and are managed under a framework of government regulations and industry practices that are already in place. The latter are less well understood and need further research, as discussed later in this chapter. Public health issues relate to the design, manufacture, and operation of many aspects of aviation, including the aircraft, airlines, airports, regulatory agencies, and their associated passengers and workers.

Perceived impacts to public health from aviation have largely centered on noise and air quality, but concerns over climate change, water quality, and solid or hazardous wastes have also been raised. Noise impacts are currently quantified by the number of people exposed to various noise levels due to aircraft ground and air operations. The EDMS is used to assess the air quality impacts of airport emission sources, and it will soon be replaced by the more complete AEDT to quantify and model the dispersion of various emissions species. Using the emissions inventory of gaseous and particle species from these tools, systemwide human health impacts are quantified using the Community Multiscale Air Quality (CMAQ) modeling system, maintained by the FAA.

The spread of communicable diseases is another topic in aviation public health. Airlines and airports have played a public role in dealing with a variety of food and vector-borne outbreaks, and these are generally dealt with by a variety of regulations and best practices in aircraft and airport restroom cleaning, signing, air circulation standards, and indoor air and water quality standards. Other occupational issues include the level of cabin oxygen at altitude, exposure to hazardous air pollutants in ramp areas, repetitive stress injuries, and radiation associated with both high-altitude flying and airport security checkpoint screening devices.

Emergency management plans, sometimes called business continuity plans, usually contain planning scenarios for various kinds of public health incidents or considerations. In addition to the scenario of a global pandemic requiring aircraft or passengers to be quarantined, there are other public health concerns addressed in these plans for handling large numbers of people overnight for extended time periods, such as food, water, toiletries, blankets, counseling, telecommunications, and the like. These practices are common in emergency management practice; public health considerations are integrated into both the operational and emergency planning aspects of aviation.

3.4.3 FUTURE VISION

The future vision for public health in aviation looks to the ways that public health is affected by aviation more broadly, and how new ideas for design, management, and operation of aviation systems can lead to a healthier society in the future. For example, public health efforts in aviation could address increasing physical activity, improving healthy food and beverage availability, access to medical care and education, and adopting formal programs of health impact assessments (HIAs).

Airports and airlines are large public gathering places, providing many opportunities for public services and public education. Airports and airlines need to continue working with research organizations to better understand public health impacts while simultaneously translating the information so that various stakeholders, especially the public, can better understand these health impacts. Also, access to medical equipment and services will continue to improve as these opportunities are developed.

It is still difficult for airports to provide the public with clear answers to questions surrounding public health. For example, although noise impacts related to sleep disturbance and learning have been studied, no conclusive results currently exist. Also, although emission rates and concentrations of air contaminants are modeled with stated approximations, there is still much to understand on source characterization of particulate matter (PM) emissions and the exposure to pollutants that are modulated by external factors such as location, meteorology, etc., of each airport environment. In addition, the characteristics of the surrounding population also need to be taken into account, such as age, socioeconomics, and predisposition to sickness and disease from certain pollutants. While systemwide health impacts due to PM and ozone are being routinely quantified using CMAQ, estimation of airport specific impacts need further research and modeling.

Along with direct impacts, there are also various indirect ones caused by the presence of the airport. One of the main sources of these indirect impacts is the surrounding roadways. With increased traffic, increases in exposure to traffic noise, air pollutants, stormwater runoff, etc., can occur. Other less visible, indirect public health impacts may arise from the increased risk of accidents, disease, and other factors from living within a crowded location. These impacts should be viewed on balance with the socioeconomic benefits that aviation provides, but these types of impacts add to the overall concerns raised by the public, whether the impacts are just perceived or real.

In addition, the obesity crisis is gaining an increased focus in public health and is widely agreed to be the result of unhealthy food choices, large portion sizes, and increasingly sedentary lifestyles. The vision of the future includes airports and airlines where physical activity is increasingly provided for, and healthy food and beverage choices are widely available. There are many examples today of airports where walking distances have been deliberately minimized by powered conveyances, and whose food concessions lack easily transportable healthy options. Even the availability of drinking fountains is not standard in all airports across the world.

Finally, a systematic process of HIAs will increasingly be used for decision making in large organizations, leading to new features of aircraft and airport design and operation that benefit public health.

3.4.4 RESEARCH NEEDS

The research needs for public health in aviation follow along the lines of the topics in the future vision described above, as follows:

- **Airport PM emissions and exposure characteristics** need to be further studied. In addition to exposure levels (e.g., atmospheric concentrations), full epidemiological studies need to be conducted in order to comprehensively understand both systemwide and airport-specific impacts. Such studies need to include both direct and indirect impacts using observational and modeling approaches.
- **New metrics and methods to explain the impacts need to be developed.** For example, the development of supplemental metrics for noise (i.e., beyond the standard 65 DNL) provides an indication of the types of new metrics that may be necessary to help convey the impacts to a lay audience.
- **Physical activity:** design and operational best practices for providing employees and travelers with the greatest options for physical activity in all phases of aviation include getting to and from the airport, using the airport, and exercising while airborne. These include transit and nonmotorized access to airports, stairs and walkways as alternatives to escalators, moving sidewalks and shuttle trains, passive exercise equipment in gate areas, and exercise opportunities for passengers while on board aircraft. All of these practices need additional research and feasibility testing.
- **Healthy food:** one of the challenges of offering healthy food to travelers is the need for packaging and preservation of heat and cold while the traveler moves from terminal, between

terminals, and onto aircraft. Airlines providing meals to passengers on board aircraft also have a set of preservation and preparation challenges. Research is needed into ways to improve the availability and portability of healthy food options and ways to incentivize providing healthy food in airline and concession agreements.

- **Accommodation of diverse needs:** the changes in the mix of ages, gender, language, religious, and physical accessibility needs of travelers and employees is a constant challenge and opportunity for the aviation industry. Research is needed in many areas of understanding the demographic shifts, accommodating cultural and religious practices and expectations, overcoming language and technology barriers, and improving physical accessibility.
- **Obesity impacts:** dealing with obesity is a specific challenge to aviation, because of the effect of payload on aircraft performance and the traditionally uniform size of airline and airport seating. Research is needed on the effects of obese passengers on the costs and experience of travel, options for mitigating these effects, and the results of early industry experiments such as charging passengers a ticket price by weight, or charging for the use of an extra seat.
- **HIA** is a formal analysis process, similar to an EIS, which has begun to be used on large development projects. So far there are no regulatory requirements for HIAs, as there are for EISs, but the process of conducting an HIA is designed to incorporate public health objectives in all aspects of a project's design and operation. Research is needed on the applicability of HIAs to aviation decision making, alternatives for funding and leading the analysis, and recommendations for incorporating the HIA components into traditional project and business planning processes.
- **Resilience to changes:** in much the same way as airlines can never lose sight of their customers and airports can never stop working with their neighboring communities, aviation can never stop considering its impact on public health and proactively being involved in improvements. Research is needed on how to improve the collaboration between aviation and public health practitioners, and to keep learning about, and adapting to, emerging issues in both spheres. Research is also needed on ways to monitor the results of public health actions taken by the aviation industry, the new scientific findings being discovered, and actions being taken by other industries, to create a process of continuing improvement. It is likely that some of this activity will take place in industry associations and regulatory bodies, and some will take place in specific airlines, airports, and other industry players.

3.4.5 ADDITIONAL RESOURCES

The field of aviation public health has a long history, beginning with the Aerospace Medical Association, and the Centers for Disease Control and Prevention, in Atlanta, Georgia. The National Research Council released a comprehensive report on the use of HIAs in 2011. Web links to these references along with related TRB Airport Cooperative Research Program reports are listed below.

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ACRP Report 91: Infectious Disease Mitigation in Airports and on Aircraft. Transportation Research Board of the National Academies, Washington, D.C., 2013. Available at http://www.trb.org/main/blurbs/169466.aspx.

ACRP Report CD-137: The Vector-Borne Disease Airport Importation Risk Tool. Available at http://www.trb.org/main/blurbs/169301.aspx.

Aerospace Medical Association. http://www.asma.org.

Centers for Disease Control and Prevention. Healthy Places website. Available at http://www.cdc.gov/healthyplaces.

Conference Proceedings 41: Interagency–Aviation Industry Collaboration on Planning for Pandemic Outbreaks. Transportation Research Board of the National Academies, Washington, D.C., 2008. Available at http://www.trb.org/Main/Public/Blurbs/157095.aspx.

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