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Critical Issues in Aviation and the Environment 2021

Prepared by

Transportation Research Board
Committee on Environmental Issues in Aviation

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The **Transportation Research Board** is distributing this E-Circular to make the information contained herein available for use by individual practitioners in state and local transportation agencies, researchers in academic institutions, and other members of the transportation research community. The information in this E-Circular was taken directly from the submission of the authors. This document is not a report of the National Academies of Sciences, Engineering, and Medicine. It should be noted that although this E-Circular is titled 2021, much of the research and content development was completed over prior years. While the authors tried to incorporate updates throughout the editing timeframe, at some point the authors and editors needed to conclude the process to accept or add new content. For example, the E-Circular does not discuss the resulting changes from the 2020 covid-19 pandemic or President Biden and his administration's focus on the environment and climate change.

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Introduction

The Transportation Research Board (TRB) Committee on Environmental Issues in Aviation (AV030) focuses on environmental concerns central to airport planning, design, construction, and operation, as well as related aviation system and aviation technology development. In 2004, the committee issued its first report on *Critical Issues in Aviation and the Environment*. The committee continued to update and revise this report in subsequent years (2005, 2009, 2011, and 2014) to capture the environmental priorities, concerns, and research needs in the aviation industry. This revision updates and expands upon the previous reports with a focus on cross-disciplines to review subjects of interest to the civil aviation community.

Similar to previous reports, the 2021 *Critical Issues in Aviation and the Environment* report includes chapters grouped into three general categories: (1) environmental impacts of aviation on human and natural resources, (2) sustainable solutions to address environmental challenges, and (3) processes and tools for implementing sustainable solutions. The development and operation of aircraft and airports is influenced by the role of the environment and sustainability. The aviation industry and federal government is investing significant resources to better understand and minimize the potential environmental impacts related to aviation. In some cases, environmental concerns have become a fundamental constraint to increases in aviation system capacity. Constrained capacity can further exacerbate environmental problems related to noise and local air quality impacts. This report strives to summarize the insight and progress made to date and provides recommendations for additional research to help achieve and mitigate environmental impacts.

This *Critical Issues in Aviation and the Environment* report consists of eight sections representing the authoring experts' opinions on issues addressing 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 previous editions, the focus of this report is the state of science and identification of research needs having the greatest potential to yield benefits in the coming years. Policy updates are included where appropriate. Each section is divided into subsections with the following objectives:

- A description of the critical issues in the subject area.
- A discussion of the current state of practice, research, and policy.
- An overview of the vision for future capabilities addressing the critical issues.
- An identification of research needs to help achieve the vision.

This report focuses on research conducted in the United States, although international activities are incorporated where public or private entities in this country are closely involved. The authors collected a wide range of published and unpublished material, public information, and individual contributions to prepare these sections, as noted in the references at the end of each section. Due to scope constraints, each and every critical issue attributed to a section is not addressed; however, the authors strived to provide details for the most pressing concerns. For example, this report does not address land use development near airports although this concern represents a major constraint on future aviation activity and for which effective controls are being implemented and developed.

The critical issues included in *Critical Issues in Aviation and the Environment 2021* have evolved over time, including their importance relative to each other, and will continue to do so. For example, while aircraft noise impacts once were preeminent among the operational environmental issues associated with aviation, air quality emissions and climate concerns continue to reach a nearly equivalent status. Water quality issues remain an important critical issue since the first critical issues paper published in 2004. In addition, the past decade continues to demonstrate a growth in the development and advancement of aviation sustainable aviation fuels.

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

1.1.1.1 State of the Industry

Historically, there has been a substantial reduction in the number of people exposed to significant levels of aircraft noise (based on the longstanding federal standard of Day-Night Average Sound Level (DNL) 65 decibels [dB]). However, even with this success, aviation noise is and remains a concern for many communities. To promote ways in which to better balance the benefits and adverse effects of aviation on airport communities, the Federal Aviation Administration (FAA) continues work to improve its means of understanding and reducing the effects of aircraft noise exposure.[1] **FIGURE 1-1** presents the United States (U.S.) population exposed to noise levels of DNL 65 dB and above compared to aviation activity as measured by passenger enplanements.[2]

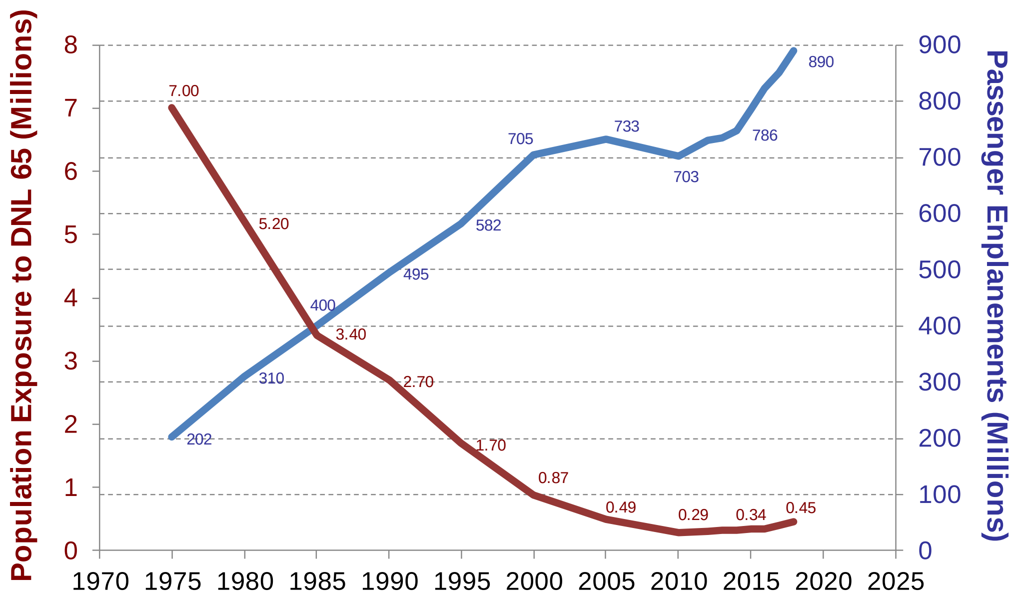

FIGURE 1-1 Exposure to noise levels.

The aviation industry has made major strides in alleviating aircraft noise concerns for a majority of the population through quieter aircraft and development of noise abatement procedures. However, some of those still experiencing aircraft noise continue to express concern, engage their local officials, and request flight paths changes.[3] FAA has undertaken a major review of the appropriate level of DNL to describe community annoyance in the Aviation Sustainability Center (ASCENT) program. Furthermore, continued aviation growth, new entrants into the National Airspace System (NAS), such as uncrewed aircraft systems (UAS), urban air mobility, commercial space applications, and a renewed focus on civil supersonic travel, pose new challenges in noise policy, land use compatibility and mitigation of aviation noise impacts. A sampling of the industry's challenges is discussed in the following subsections.

1.1.1.2 Performance Based Navigation

Air traffic management performance based navigation (PBN) procedures have the potential to reduce fuel consumption, decrease overall flight time, increase safety, and reduce overall carbon emissions. The U.S. Federal Aviation Administration (FAA) continues to modernize the NAS by developing and implementing PBN procedures at airports, including via Metroplex projects (implementing PBN procedures in the airspace surrounding select major metropolitan areas) and on a single-site basis. Aviation industry stakeholders are experiencing an increasing level of public debate, noise complaints, interest from elected officials, and litigation related to the concentration of flight operations due to PBN procedure implementation. These factors continue to provide challenges to meeting global aviation demand and improving airport infrastructure.

1.1.1.3 Uncrewed Aircraft Systems

Interest continues to grow in the use of UAS within the NAS. Civil and commercial UAS applications, especially at low altitudes, span a wide range of sectors including infrastructure inspection, survey, monitoring, package delivery, and emergency management. The FAA estimates that the entire small UAS (sUAS) fleet, including both hobbyist and commercial uses, will reach 1.9 to 2.3 million vehicles by 2021.[4,5]

The FAA is working to integrate UAS into the safest, most complex aerospace system in the world. Currently, FAA only authorizes sUAS weighing no more than 55 pounds to operate commercially, under 14 Code of Federal Regulations (CFR) Part 107. sUAS have a low energy output and are limited by safety parameters such as maintaining visual line of sight (VLOS), prohibitions of flight over people, daylight operational restrictions, requirements to yield right of way to other aircraft, maximum ground speed of 100 miles per hour (mph), and flight at a maximum altitude of 400 feet above ground level (AGL). Due to the weight limitation, sUAS do not significantly implicate noise and air quality concerns, as compared with traditional commercial and general aviation (GA) aircraft. However, with increasing use, including unique use cases, the acoustic properties and potential environmental impacts of UAS require continued consideration.

1.1.1.4 Urban Air Mobility

Urban Air Mobility (UAM) is a rapidly emerging concept of air transportation that could revolutionize the way people move within and around cities by shortening commute times, bypassing ground congestion, and enabling point-to-point flights across cities. In recent years, several companies have designed and tested enabling elements of this concept, including prototypes of Vertical Takeoff Landing (VTOL) capable vehicles, understanding of operational concepts, and development of potential business models. As cities become more congested, the demand for air taxi vehicles is increasing as a faster way for people to get from one location to another. Such operations are already provided by businesses such as Blade, which offers helicopter service from urban locations to airports and other locations. In the future, helicopters could be replaced by electric vehicles, and ultimately by electric UAS. The proliferation of UAM operations is likely to cause the concerns similar to UAS, but in vehicles that are much larger than the sUAS.

1.1.1.5 Civil Supersonic Operations

As notable advances in engine technology, aircraft design and new materials have opened the door to potentially economically feasible supersonic travel, several private companies are developing new civil supersonic aircraft. Current regulations prohibit overland supersonic civil flights in the United States. Considerable efforts are being undertaken to update the policy and regulatory environment, and to capture potential environmental impacts of supersonic travel. Notably, in March 2020, FAA issued a notice of proposed rulemaking for supersonic aircraft to add landing and takeoff noise standards for a certain new class of supersonic airplanes.[6] 14 CFR Part 91 prohibits overland supersonic flight, but allows flights for test and development of new aircraft, although the procedures and guidance require modification. Streamlining of the process to obtain special authorization would allow increased flight testing, enabling more data to be gathered that will inform the efforts to promulgate noise regulations for the certification of supersonic aircraft.

1.1.1.6 Commercial Space Applications

Considerable research and development efforts have been conducted to support an emerging industry of commercial space transportation. Since 1989, more than 300 operations have been licensed or permitted by the FAA.[7] The FAA Office of Commercial Space Transportation and the Commercial Space Transportation Advisory Committee (COMSTAC) forecasted an average annual demand of 30 commercial launches for each year between 2014 and 2023.[8] 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 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; there is a commensurate requirement for accurate acoustical assessment tools.

1.1.1.7 Increased Community Involvement

Community involvement has become a high priority for aviation stakeholders, including the FAA and airport operators. In 2016, the FAA released an updated *Community Involvement Manual*, which outlines tools and techniques helpful in complying with the public participation elements of the National Environmental Policy Act (NEPA) and other environmental laws.[9] Airport operators continue to engage stakeholders in the voluntary 14 CFR Part 150 Noise Compatibility Program, in an effort to mitigate existing and future incompatible land uses.

A continuing challenge for the development of air traffic procedures is working with communities affected by the changes in aircraft noise resulting from new, streamlined, precise paths used by PBN. Community concerns can lead to expanded scope, extended environmental assessments, increased project duration and costs, and potential legal challenges.

Airport operators, particularly those at which PBN procedures have been implemented, have formed community roundtables, many of which are approaching aviation noise from a traditional noise abatement standpoint, and are affecting change through policy, research and legislative efforts. With FAA technical information and advice, many roundtables are establishing ongoing dialogues and encouraging cooperative decision-making, an approach that allows all interested parties the opportunity to develop a collaborative localized plan.[10]

In response to an increase in noise complaints to the agency, FAA has implemented the Noise Complaint Initiative (NCI), which has resulted in improved and consistent agency-wide procedures and systems to more efficiently and effectively respond to public aircraft noise complaints and inquiries. These include the establishment of (1) clearly assigned roles and responsibilities of FAA personnel in responding to public noise complaints/inquires; (2) an internal noise complaint/inquiry repository with details on processes, policies, related studies, points of contacts; and (3) an FAA Noise Complaint and Inquiry Database and Tracking System (Noise Portal).

1.1.1.8 Summary

These challenges, in addition to increasing attention to helicopter operations, overflights of U.S. National Parks and sustained growth in aviation activity, pose notable challenges to the aviation industry's ability to meet forecast growth conditions. Noise research continues to play a major role in an improved understanding of the potential noise impact on people and natural resources. This section focuses on critical issues in civil aviation noise, including a discussion of recent trends and emerging issues, related forums and ongoing research, and research required to assist with environmental decision-making.

1.1.2 CURRENT STATE

Critical research continues to be undertaken by numerous aviation stakeholders, and new policy initiatives and legislation reflect the changing industry and increased attention to noise. The FAA sponsors research and implements policy both as an independent agency and in conjunction with other federal agencies and academic institutions, incorporating legislative mandates, such as the research and policy direction provided in the *FAA Reauthorization Act of 2018*. This section highlights some of the key organizations, activities, studies and legislation regarding policy, noise impacts, and technology.

1.1.2.1 2018 FICAN Research Review of Selected Aviation Noise Issues

In April 2018, the Federal Inter Agency Committee on Aviation Noise (FICAN) published the *Research Review of Selected Aviation Noise Issues*.[11] This publication summarizes studies by American and international researchers conducted since the last FICAN report in 1992,[12] reviews the findings of the 1992 report, makes updated recommendations, and identifies a number of aviation noise issues that merit future attention. Further findings of the FICAN report are discussed in later portions of this section.

1.1.2.2 97th Annual Meeting of the Transportation Research Board, 2018

During the 97th Annual Meeting of theTransportation Research Board (TRB) in 2018, the FAA and Federal Transit Administration (FTA) participated in a session entitled "Health Impacts of Transportation Noise." The ongoing research directions and implications for aviation, transit and highway noise were discussed, including needs, conceptual research questions and recommendations for future noise-health research. The session was based, in part, on findings of an FAA 2017 workshop, which included a review of relevant topics and the most recent findings.[13]

1.1.2.3 U.S. Department of Transportation Health in Transportation Working Group

U.S. Department of Transportation (DOT) Health in Transportation (HinT) Working Group, which includes FAA, FTA, the Federal Highway Administration (FHWA), the National Highway Traffic Safety Administration (NHTSA), and the U.S. DOT Office of the Secretary of Transportation (OST), was formed several years ago to develop a common understanding of health in transportation; identify aspects of existing U.S. DOT programs that relate to health; and address stakeholders' health-related concerns and communicate these concerns within the agency. The U.S. DOT's HinT Annual Reports[14] provide an overview of the Working Group's activities, summarize other U.S. DOT health-related accomplishments, and document the progress towards meeting the goals laid out in previous annual reports.

1.1.2.4 FAA Reauthorization Act of 2018

The *FAA Reauthorization Act of 2018*, passed by Congress on October 3, 2018, devotes an entire section[15] to airport noise and environmental streamlining, reflecting a heightened awareness and interest from elected officials. Many items specifically focus on research. Among the 12 provisions that address noise are:

- the requirement that FAA consider dispersal of new area navigation (RNAV) departure procedures below 6,000 feet under certain conditions,
- a requirement to report on methods for improving community involvement in Next Generation Air Transportation System (NextGen),[16]
- review and evaluation of existing studies of the relationship between jet aircraft approach and departure speeds and corresponding noise impacts on overflown communities,
- an evaluation of the potential phase-out of Stage 3 aircraft, and
- engaging a university partner to study the "incremental health impacts on residents living partly or wholly underneath flight paths most frequently used by aircraft flying at an altitude lower than 10,000 feet, including during takeoff and landing."

1.1.2.5 FAA UAS Symposium

The recent *FAA Reauthorization Act of 2018* also served as a significant step forward for the FAA and the UAS (drone) industry, providing clarity and direction on creating the next rules and regulations for their integration. The FAA and the Association for Unmanned Vehicle Systems International (AUVSI) continue to co-sponsor the annual FAA UAS Symposium. Emphasis in the UAS and UAM market continues to be on the safe integration into the NAS, while discussions on annoyance, community acceptance, and the appropriateness of existing noise metrics continue.

1.1.2.6 ASCENT

The Aviation Sustainability Center (ASCENT), also known as the Center of Excellence for Alternative Jet Fuels and Environment, is funded by the FAA, National Aeronautics and Space Administration (NASA), the Department of Defense, Transport Canada, and the Environmental Protection Agency (EPA).[17] ASCENT comprises 16 leading United States research universities and over 60 private sector stakeholders and is committed to reducing the environmental impact of aviation. ASCENT works in partnership with international research programs, federal agencies and national laboratories.

ASCENT universities and their partners have completed research projects related to: noise mitigation, by addressing the tools used to measure noise level reduction experienced in buildings exposed to aircraft noise; civil supersonic noise standards development via assessment of low boom acoustic signatures and the causes of variability; evaluation of the appropriateness of metrics for use in noise certification and an exploratory review of social media monitoring as potential supplemental means to gauge overall community reaction to a community noise test; and enhancing aircraft design and performance assessment tools.

1.1.3 RESEARCH NEEDS

To improve understanding about environmental impacts of aviation on human and natural resources, and to support environmental policy development, an extensive body of research is currently being conducted. Topics vary from fundamental academic studies to applied guidelines useful in practice and communication.

1.1.3.1 Noise Mitigation Projects

In 2014, the FAA amended the Airport Improvement Program (AIP) Handbook to clarify guidance for the funding of noise mitigation projects to require that eligible structures not only be located within the DNL 65 dB noise contour, but also experience existing interior noise levels that are 45 dB or greater with the windows closed. This restated guidance, which places greater emphasis on the accuracy of the measurement of the existing noise level reduction (NLR), applies to ongoing residential sound insulation programs.

Determination of NLR has included both measurements of aircraft overflights as an exterior noise source and an application of an external loudspeaker methodology adapted from the American Society for Testing and Materials International (ASTM) E966 procedure.[18] Recent research has been undertaken to evaluate NLR test result dispersions, as well as variations based on local conditions.[19] This ongoing research will support airport residential sound insulation programs. Future research needs may include methods to estimate structures with high floors, estimates of indoor sound absorption and use of innovative testing methods to enhance measurement efficiency.

1.1.3.2 Aircraft Noise Certification

The FAA has adopted a new noise standard for the certain newly certificated subsonic jet airplanes and subsonic transport category large airplanes.[20] This noise standard, known domestically as Stage 5, applies to an application for a new airplane type design with a maximum certificated takeoff weight of 121,254 pounds or more on or after December 31, 2017; or with maximum certificated takeoff weight of less than 121,254 pounds on or after December 31, 2020. This change sets a lower noise limit for newly certificated airplanes and harmonizes the noise certification standards for airplanes certificated in the United States with those certificated under international standards.

1.1.3.3 Noise Prediction Tools

The FAA's Aviation Environmental Design Tool (AEDT), initially released in 2015, has replaced a series of legacy FAA modeling tools.[21] AEDT presents a fundamentally different system architecture, design and capabilities, which allow the user to simultaneously predict aviation noise, fuel consumption, and emissions within a common interface and common inputs. AEDT has achieved widespread use for research efforts, 14 CFR Part 150 studies at airports, and for projects in support of NEPA reviews.

In addition to FAA's ongoing development, various research projects undertaken and planned as part of the National Academy of Sciences, Engineering and Medicine Airports Cooperative Research Program (ACRP) aims to advance the state of aviation noise modeling, including topics such as improving modeling of hard, soft and mixed ground surfaces,[22] arrival and departure profiles,[23] and reflection and diffraction from terrain.[24]

While industry and research use of AEDT represents an important advancement in modeling technology, future research and development needs exist. Incorporation of aircraft configuration, including thrust and speed, and methods to account for variable flap settings, needs to be addressed. Reliance on stage length as a surrogate for aircraft weight needs to be better understood, as does modeling accuracy beyond the DNL 65 dB level. New entrants, including supersonic aircraft, need to be included.

1.1.3.4 Noise Impacts on People

Among the range of potential adverse impacts on people associated with aviation noise are community annoyance, children's learning, sleep disturbance, and health, particularly related to cardiovascular disease. In recent years, both FICAN and the Committee for Aviation Environmental Protection (CAEP) of the International Civil Aviation Organization (ICAO) Impact and Science Group have prepared reviews of the state of understanding of potential health impacts.[25] FAA, both in conjunction with ASCENT and independently, continues to evaluate potential health impacts.[26]

Annoyance: Since the 1970's, land use compatibility and the significance of noise impacts have been evaluated in terms of annoyance. Annoyance is a cumulative measure of the general adverse reaction of people to noise that causes interference with speech, sleep, the desire for a tranquil environment, and the ability to use the telephone, radio, or television satisfactorily.

In 2014, FAA initiated a national survey to measure changes to public perception to aircraft noise. The survey, which includes responses from over 10,000 people living near 20 airports, is a part of the FAA's broader research portfolio related to aircraft noise. The survey results and a draft report are in the process of being reviewed by the FAA in coordination with U.S. DOT and other federal agencies.

The appropriateness of the DNL 65 dB metric continues to be challenged, including by international studies and the World Health Organization (Europe).[27] The research results of the FAA's annoyance survey will provide empirical data that could be used to inform any potential updates to or validation of national noise policy. This is required by Section 187 of the *FAA Reauthorization Act of 2018*, which requires FAA to complete "ongoing review of the relationship between aircraft noise exposure and its effects on communities."[28]

Sleep Disturbance: Aircraft noise can disturb sleep, interfere with resident's rest and may contribute to long-term health consequences. FAA is undertaking research to develop and use an inexpensive, scientifically sound methodology to obtain objective measures of sleep disturbance from aircraft noise, and to use that methodology to collect nationally representative information on the relationship between aircraft noise exposure and sleep disturbance. ASCENT Project 17 evaluated methods of monitoring sleep at major U.S. airports.[29]

FAA is continuing work on developing a relationship between aircraft noise exposure and sleep disturbance, which supports FICAN's 2018 Research Review.

Children's Learning: Multiple research studies have been undertaken with the objective of understanding the potential effects of aviation noise exposure on children's learning. One study found that a small, but statistically significant, correlation exists between noise exposure and student test scores;[30] a survey of teachers in aircraft noise-exposed schools suggested that even moderate levels of aircraft noise exposure may impact children's learning experiences.[31]

To evaluate the effects of aircraft noise on children's learning, FICAN recommended including predictions of school-day noise exposure, as measured by 8-hour Leq, until other research suggests a more appropriate metric, and that the acoustic measurements of classroom noise as well as new classroom acoustic design follow guidelines presented by American National Standards Institute (ANSI) S12.60-2002, *Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools*.[32]

Cardiovascular Health: As one of multiple non-auditory health impacts, cardiovascular effects from aircraft noise are receiving attention, due in part to the theory that long-term exposure to environmental noise may affect the human cardiovascular system and thus contribute to disease. To date, few studies have focused on association between long-term exposure to transportation noise and cardiovascular health. ASCENT is conducting research with a goal of determining the association between long-term exposure to transportation noise and cardiovascular outcome by evaluating historic, modeled noise levels in conjunction with existing epidemiological data. This effort aims to determine what, if any, correlation exists between cardiovascular disease and aviation noise.[33]

FICAN identified that research needs to be conducted to quantify relationships between aircraft noise level (dose) and the health outcome in question (effect). FAA's work to support this effort is ongoing, with work expected to be published in 2022.

1.1.3.5 UAS and UAM

While safety remains the first priority in UAS/UAM operations, environmental considerations must be addressed. There are a number of important UAS-related research initiatives underway, including development of a noise database for these aircraft for use in noise modeling, identification of vehicles and operations with the highest environmental impact, definition of repeatability in recorded noise data, assessment of metrics suitable for different vehicle types, and development of a framework for future measurement and certification.

Some of these research efforts are ongoing at UAS test sites using federal and corporate funding. For example, ACRP project 03-50, "An Airport-Centric Study of the Urban Air Mobility Market," is analyzing UAS environmental issues in conjunction with the UAM markets, including technologies and a regulation framework.[34] Use cases (e.g., passenger, cargo, and air ambulance), activity projections, and financial viability will include potential short- and long-term UAM impacts and opportunities for the airport industry.

1.1.3.6 Civil Supersonic Aircraft

While many regulatory and technical hurdles remain, the U.S. DOT and FAA are taking steps to support the development of civil supersonic aircraft and update associated regulatory framework. Within the regulatory environment, FAA is engaged in two activities: a proposed rule for landing and takeoff noise certification of supersonic aircraft, and a proposed rule to streamline and clarify the procedures to obtain special flight authorization for conducting supersonic flight testing in the United States. According to FAA, a rulemaking activity related to landing and takeoff noise certification of supersonic aircraft will determine the technological and economic basis that supports noise level requirements that are appropriate for supersonic aircraft.

NASA continues to lead the investigation of low boom technologies and associated community reaction. Research completed under the Waveforms and Sonic boom Perception and Response (WSPR)[35] program, using NASA's modified F/A-18, aided in the development of data collection methods for future public perception studies. Updated tests were performed in 2018 under the Quiet Supersonic Flights program. As part of NASA's Low-Boom Flight Demonstration program, construction continues on a purpose-built aircraft for further research.

ICAO CAEP has agreed to conduct an "an exploratory study" on civil supersonic aircraft technology during the CAEP/12 cycle. This review will provide a better understanding of the potential impact of supersonic aircraft on noise, air quality, and the climate, as well as any interdependencies.[36]

1.1.3.7 Commercial Space

A number of airports and other facilities wish to support the growing demand for commercial space operations and are seeking launch site operator licenses from the FAA. With the commercial space industry developing rapidly, the gap in industry's ability to address rocket launch community noise remains, including both the identification of suitable metrics and modeling capabilities.

There is currently no adequate metric for assessing the noise impact of commercial space vehicle operations, and A-weighted noise metrics used for civil aviation are not particularly suitable for rocket noise estimation. Due to the significant low frequency commercial space vehicle noise energy, future commercial space noise models will need to consider metrics suitable to describe the unique sound characteristics of both launches and sonic booms, and community annoyance. These future models will include low frequency vibration and rattle components, and sonic boom modeling will be further advanced by including atmospheric variability and turbulence effects.

AEDT currently does not have the capability to predict commercial space operations noise and sonic booms. Modeling commercial space operations is notably complex due to the wide variety of vehicles and operational scenarios, many of which are still in the design phase. Sonic boom and rocket noise modeling will require the design of an internationally accepted propagation modeling methodology that will permit computation of metrics at reference conditions from measurements. Initial efforts towards this end were made through *ACRP Web-Only Document 33: Commercial Space Operations Noise and Sonic Boom Modeling and Analysis.* This project focused on developing a set of noise and sonic boom models suitable for environmental analysis of commercial space operations and airport/space launch site facilities that are either compatible with or can be integrated into AEDT. *ACRP Research Report 183: User Guides for Noise Modeling of Commercial Space Operations—RUMBLE and PCBoom*, provides guidance on using the RUMBLE model for predicting rocket noise and PCBoom4, which has been modified to predict sonic booms from commercial space operations.[37, 38]

In addition to these obstacles, noise data for commercial space launch vehicles have not yet been compiled into one credible database and uniform format. As an initial effort, *ACRP Web-Only Document 47: Commercial Space Operations Noise and Sonic Boom Measurements*, gathered empirical data to validate and to populate the database.[39] The objectives of this research were to develop a community noise measurement protocol for commercial space operations noise and sonic booms, conduct a measurement campaign of actual space operations, and compile a database of space operations noise and sonic booms that will serve as model source characteristics for the purpose of facilitating community noise model development and validation. Measurement protocols for compiling a dataset will be built based on findings from this research.

Updates to FAA policy may also be needed to be undertaken to encompass both the known and unknown range of expected operations and vehicles.

1.1.3.8 Helicopter Noise

Helicopter noise remains a source of community annoyance, as evidenced by increasing opposition to helicopter operations in both the New York and Los Angeles areas. Helicopter noise sources include, among others, helicopter tour and charter operators, as well as police and air ambulance services. Numerous outreach and research efforts are ongoing.

The Helicopter Association International (HAI) developed a Fly Neighborly Program, which is supported by numerous private and public partners, including the FAA.[40] The program dates to the early 1980’s when the first Fly Neighborly Guidelines were developed and published, and HAI continues to formulate guidance and materials based on helicopter noise testing by manufacturers and government research organizations. More recently, Fly Neighborly has been incorporated into an iFlyQuiet program supported by the FAA, HAI, and the Vertical Flight Society (VFS). The program includes extensive testing conducted by the FAA and NASA to develop Fly Neighborly information and procedures, developing additional promotional materials, and pilot training programs.

Helicopter noise differs from fixed-wing aircraft noise in many ways, including a different frequency content, sound level onset and decay rates, and duration. Additionally, helicopter operations typically occur at lower altitudes and tend to vary more than fixed-wing aircraft patterns. In a 2004 Report to Congress, the FAA identified the need to develop models for characterizing human responses to helicopter noise. *ACRP Research Report 181: Assessing Community Annoyance of Helicopter Noise*, attempted to develop a dose-response curve for helicopter noise exposure, although the sites selected for surveys were exposed to relatively low levels of helicopter noise.[41] Further studies are needed in areas that experience higher levels of helicopter noise exposure.

To advance the state of modeling, specifically for the development of noise abatement procedures for existing and proposed rotorcraft, Pennsylvania State University has developed a first principles helicopter noise prediction model (CHARM/HELOSIM/PUS-WOPWOP). The model is currently undergoing validation and refinements and will include model development of UAM and UAS.

FAA and NASA continue noise testing and validation efforts for specific rotorcraft. At Eglin Air Force Base and Amadee Army Airfield, in September 2017, a number of rotorcraft (R-44, R-66, Bell 206LIII, Bell 407, AS350, and an EC130) were selected to represent categories that included variations in rotorcraft size, number of main rotor blades, differences in tail rotor technology, and differences in engine types. Initial validation has shown that the noise prediction system agrees with test data within 2 to 4 SEL dBA (often <2). Testing continued in 2019 at Coyle Field New Jersey, where three aircraft were selected to represent heavier rotorcraft: Bell 205, AW139, and S-76A.

Future work regarding helicopter noise includes, in part, developing a real-time prediction capability, developing advanced noise abatement procedures tailored to individual helicopters, extending the modeling effort to include UAM and UAS, analyzing the 2019 test data, and additional helicopter testing to obtain data for helicopters not included in the database.

1.1.3.9 National Parks

Aircraft noise in national parks continues to be an area of concern warranting special consideration in the evaluation of aircraft noise impacts. Perception of noise is based on a visitor's expectations of natural quiet, type of activity being undertaken, noise source characteristics, and other factors. The National Park Service continues to develop air tour management plans as part of its mission to protect the natural soundscape, as well as continuing to measure and map sources of noise to better understand a park's existing acoustic environment.[42]

Current metrics designed to protect human health and welfare, including DNL, may not adequately address the effects of noise on the experience of park visitors. Studies have evaluated the relationship between aircraft noise annoyance from various airport sources and park visitors engaged in both day and overnight park activities.[43] Backcountry visitor surveys have shown that percent time audible is a suitable noise metric where an expectation of natural quiet may be present.[44]

While considerable research has been done on the development of dose-response relationships on visitor response to air tour noise, FICAN's 2018 Research Review indicated a need to engage in research regarding visitor experiences and determining appropriate sample sizes. New research topics include the restorative benefits of quiet environments and the sounds of nature, whether aircraft noise interferes with the historical or cultural significance of some national parks, and whether visitors feel their opportunities to experience the historical and cultural resources in parks have been impacted.

1.1.3.10 Conclusion

Collaborative efforts by engaged stakeholders over decades has enabled steady progress towards making the skies quieter. However, the NAS landscape continues to change with aviation growth, new issues, and the introduction of new technologies.

New vehicles types can be louder or quieter, can be closer or higher, and fly more or less frequently compared to existing aircraft. Therefore, new and credible data are required to provide information for the reevaluation of existing noise policy on behalf of all stakeholders, including residents living near airports or under flight paths. The pace of change continues to increase, and, as this section has suggested, research and development efforts are ongoing in an effort to address these critical issues.

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1.2
Air Quality

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1.2.1 INTRODUCTION

Air emissions of criteria and hazardous pollutants, and associated impacts from aircraft-related sources continue to be prominent issues facing commercial and GA airports in the United States, despite continued reductions in national emissions and the limited contribution that aircraft make to the national inventory. Trends in U.S. criteria pollutant emission inventories (i.e., nitrogen oxides [NO_x], particulate matter less than 10 microns [PM_{10}], particulate matter less than 2.5 microns [$PM_{2.5}$], sulfur dioxide [SO_2], volatile organic compounds [VOC] and carbon monoxide [CO]) are shown on **FIGURE 1-2**. The contribution made by U.S. aircraft to the 2014 National Inventory is summarized in **TABLE 1-1.**

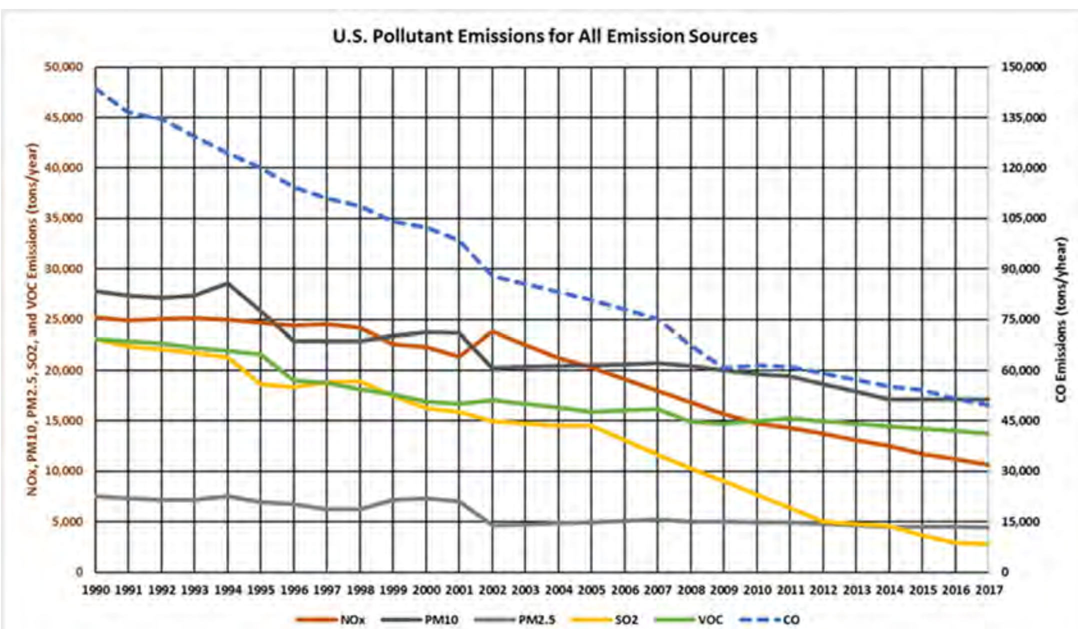

FIGURE 1-2 Criteria air pollutant emission trends in the United States, 1990–2017.[45]

TABLE 1-1 Summary of U.S. Aircraft Emissions, and Contributions to Mobile Source and Total Emissions in the United States (2014)[46]

Source	Criteria Air Pollutant Emissions (thousands of tons/year)[a]						
	CO	NO_x	PM_{10}[b]	$PM_{2.5}$	SO_2	VOC	Pb
U.S. Aircraft Emissions	412	147	10.6	9.30	16.8	47.3	0.228
U.S. Mobile Source Emissions	37,698	7,559	491	339	97	3,976	0.232
U.S. Total Emissions	72,170	13,487	18,180	5,378	4,673	55,551	0.499
U.S. Aircraft Emissions as Percent of all U.S. Mobile Source Emissions	**1.1%**	**1.9%**	**2.2%**	**2.7%**	**17.3%**	**1.2%**	**98.1%**
U.S. Aircraft Emissions as Percent of Total U.S. Emissions	**0.57%**	**1.09%**	**0.06%**	**0.17%**	**0.36%**	**0.09%**	**45.70%**

Notes:
[a] U.S. Totals do not include offshore drilling platforms and commercial marine vessel emissions outside the typical 3 to 10 nautical mile boundary defining state waters.

[b] Turbine aircraft engine emissions do not include particulate matter emissions in the size range between PM_{10} and $PM_{2.5}$. In fact, scientific measurement campaigns have reported that the size of carbon particles found in the exhaust of aircraft engines are approximately 100 nanometers in size, or smaller. This is in the ultrafine particle size range. For EPA regulatory purposes, these particles are included under the $PM_{2.5}$ air pollutant category.

As can be seen in **TABLE 1-1,** aircraft contribute only 1 percent or less to the national inventories of most criteria air pollutants. Note that on road, nonroad, locomotive, and domestic marine vessel fuels are subject to the ultra-low sulfur fuel regulations (15 parts per million [ppm]), while the range of jet fuel sulfur content is 400-800 ppm. As lead has been removed from on road/nonroad fuels and consumer products such as paint, emissions from piston-engine aircraft fueled on low-lead aviation gasoline (AvGas) currently account for almost half of the national lead inventory. Emissions from 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 nationally quite small, 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 2.5 percent per year between 2020 and 2040.[47] Increased aviation demand and activities will likely lead to an increase in aviation emissions if these emissions cannot be mitigated.

Approximately 30 percent of the busiest U.S. airports are located in nonattainment and maintenance areas for National Ambient Air Quality Standards (NAAQS) which are a component of the Clean Air Act (CAA) developed to protect public health, as established by the EPA.[48] This percentage may increase as the EPA continues to adopt increasingly stringent air quality standards, a frequent trend over the past decade. **TABLE 1-2** provides a summary of the current NAAQS of six criteria pollutants set by the EPA. The EPA promulgated new 1-hour primary NAAQS for nitrogen dioxide (NO_2) (100 ppb) and SO_2 (75 ppb) standards in 2010, which included expanding the NO_2 monitoring network intended to measure NO_2 peaks at roadways. Increased attention to short-term peak concentrations of NO_2 has led to increased pressure to better characterize peak NO_2 concentrations in airport vicinities.

TABLE 1-2 Summary of Current National Ambient Air Quality Standards[49]

Pollutant		Primary/ Secondary	Averaging Time	Level	Form
Carbon Monoxide (CO)		primary	8 hours	9 ppm	Not to be exceeded more than once per year
			1-hour	35 ppm	
Lead (Pb)		primary and secondary	Rolling 3 month average	0.15 $\mu g/m^{*3}$	Not to be exceeded
Nitrogen Dioxide(NO_2)		primary	1-hour	100 ppb	98^{th} percentile of 1-hour daily maximum concentrations, averaged over 3 years
		primary and secondary	1 year	53 ppb	Annual mean
Ozone (O_3)		primary and secondary	8 hours	0.070 ppm	Annual fourth-highest daily maximum concentrations, averaged over 3 years
Particle Pollution (PM)	$PM_{2.5}$	primary	1 year	12.0 $\mu g/m^3$	Annual mean, averaged over 3 years
		secondary	1 year	15.0 $\mu g/m^3$	Annual mean, averaged over 3 years
		primary and secondary	24 hours	35 $\mu g/m^3$	98^{th} percentile, averaged over 3 years
	PM_{10}	primary and secondary	24 hours	150 $\mu g/m^3$	Not to be exceeded more than once per year on average over 3 years
Sulfur Dioxide (SO_2)		primary	1-hour	75 ppb	99^{th} percentile of 1-hour daily maximum concentrations, averaged over 3 years
		secondary	3 hours	0.5 ppm	Not to be exceeded more than once per year

* micrograms per cubic meter

(1) In areas designated nonattainment for Pb standards prior to the promulgation of the current (2008) standards, and for which implementation plans to attain or maintain the current (2008) standards have not been submitted and approved, the previous standards (1.5 $\mu g/m^3$ as a calendar quarter average) also remain in effect.

(2) The level of the annual NO_2 standard is 0.053 ppm. Shown in terms of ppb for the purposes of clearer comparison to the 1-hour standard level.

(3) Final rule signed October 1, 2015; effective December 28, 2015. The previous (2008) O_3 standards additionally remain in effect in some areas. Revocation of the previous (2008) O_3 standards and transitioning to the current (2015) standards will be addressed in the implementation rule for the current standards.

(4) Previous SO_2 standards (0.14 ppm 24-hour and 0.03 ppm annual) will additionally remain in effect in certain areas: (1) any area for which it is not yet 1 year since the effective date of designation under the current (2010) standards, and (2) any area for which an implementation plan providing for attainment of the current (2010) standard has not been submitted and approved and which is designated nonattainment under the previous SO_2 standards or is not meeting the requirements of a State Implementation Plan (SIP) call under the previous SO_2 standards (40 CFR 50.4(3)). A SIP call is an EPA action requiring a state to resubmit all or part of its SIP to demonstrate attainment of the required NAAQS.

EPA lowered the 1998 lead standard of 1.50 $\mu g/m^3$ 10-fold to 0.15 $\mu g/m^3$ in 2008, which focused much attention on GA activity since aviation gasoline contains the additive tetraethyl lead. Initial EPA lead monitoring studies indicate that a subset of airports exceed the lead standard in close proximity to takeoff areas.[50] As a result, a number of GA 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.

Numerous sources (aircraft, stationary sources, ground support equipment [GSE], ground access vehicles [GAV], and auxiliary power units [APUs]) contribute to overall emissions originating from airport activities. In general, aircraft are the major contributors 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 percent) above 3,000 ft of altitude. Traditionally, assessments of surface air quality analyze aircraft emissions within the landing-and-takeoff (LTO) cycle between the surface and atmospheric mixing height (assumed to be 3,000 ft) determine the impact to local air quality relative to the NAAQS. Emissions above the mixing height are assumed not to impact local air quality, though they are likely to play a role in global issues. Aircraft emissions within the LTO cycle are addressed by the emission standards established by the ICAO for aircraft engines, and adopted by the United States, which are made more stringent as technology advances. For example, the trend in the certification test NO_x emission indices for aircraft turbine engines indicates that newer engines generally have lower NO_x emissions per pound of fuel consumed, as shown on **FIGURE 1-3**. Also shown on FIGURE 1-3 are the FAA Continuous Lower Energy and Emissions (CLEEN) and CLEEN II NO_x index goals that are key drivers on ongoing research into aircraft engine emission reductions. Section 2.3.2 provides additional information on CLEEN.

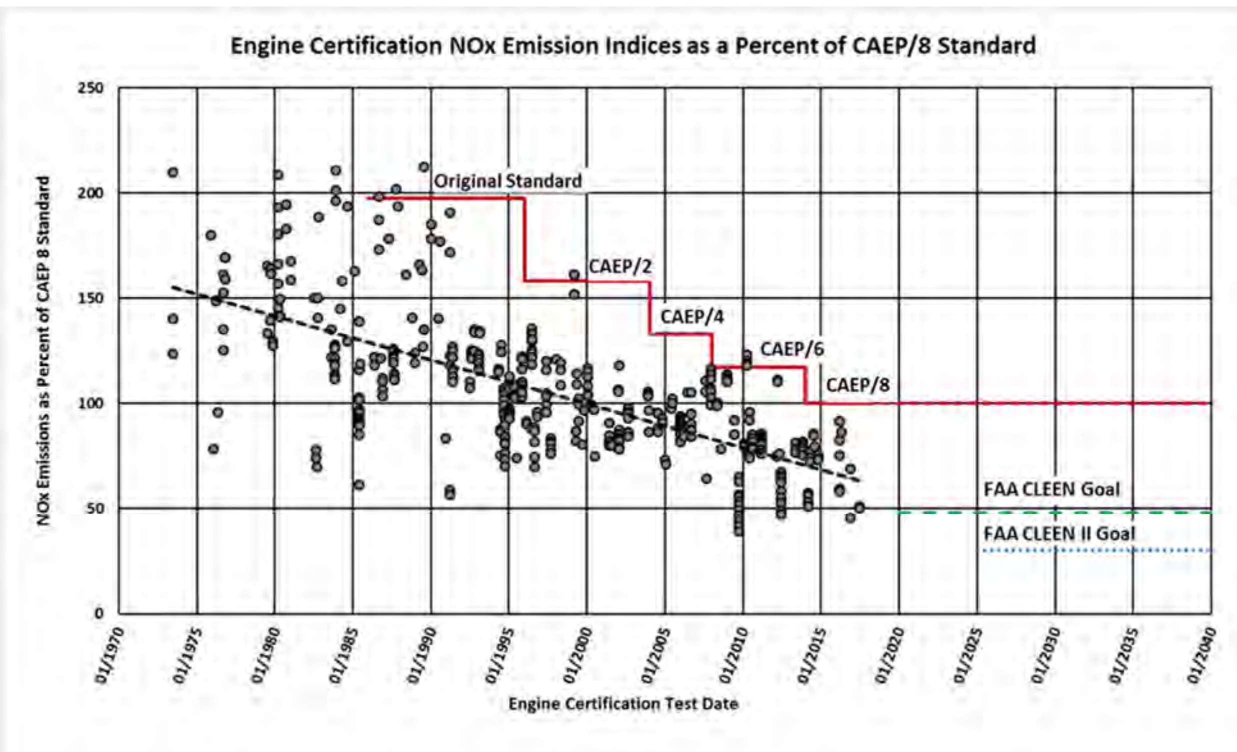

FIGURE 1-3 Aircraft engine certification NO_x emission indices as a percent of the ICAO CAEP/8 Standard, 1973–2017.[51]

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.

Air quality impacts of air pollutants, including hazardous air pollutants (HAP) released from any source, encompass a host of challenges 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.

1.2.2 CURRENT STATE

Over the past five years, substantial research has been conducted to quantify and characterize air pollutant emissions from aviation sources. This research has focused on several key issues: (1) quantifying and characterizing criteria and HAP direct emissions from large commercial in-use aircraft engines, smaller regional and GA aircraft engines, and APUs when operating on conventional and/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, including on-road traffic and parking associated with airports, (3) understanding aircraft exhaust plume chemistry and transport from cruise altitude to ground level, (4) developing improved air dispersion modeling methods for airport sources, and (5) identifying potential approaches to mitigating aviation-related impacts on air quality. The pollutants typically analyzed include particulate matter in various size ranges, NO_x, VOC, Pb, HAPs, and greenhouse gases (GHG).

1.2.2.1 Quantification and Characterization of Aviation-Related Emissions

Recent studies of aircraft emissions have focused on the following:

- Characterizing emissions from GA aircraft,
- Evaluation of thrust setting on emission indices for commercial aircraft engines,
- Characterizing particulate matter emissions from commercial aircraft engines and APU,
- Emissions from GSE, and
- Emission of ultrafine particulate matter.

1.2.2.1.1 General Aviation

Several studies and reports have been published on the measurement and analysis of emissions from GA aircraft engines, including jet-fueled turboprops and GA aircraft fueled on AvGas, which is now the largest single source of lead emissions in the United States. Regarding emissions of lead, The National Academies of Sciences, Engineering, and Medicine has published recent guidebooks on how to develop airport lead emission inventories, including an emission inventory analysis tool,[52] options for reducing lead emissions from piston-engine aircraft, [53]and how to assess lead impacts to ambient air quality from piston-engine aircraft.[54]

In addition, ACRP published an extensive report on exhaust emissions from in-use GA aircraft.[55] One key finding from the study was that the CO emissions are relatively constant over all power settings, correlating better with fuel flow than thrust setting. (See **FIGURE 1-4**.) The exhaust emissions data from GA aircraft will be incorporated into the FAA's AEDT for modeling noise and air quality impacts from aviation sources.

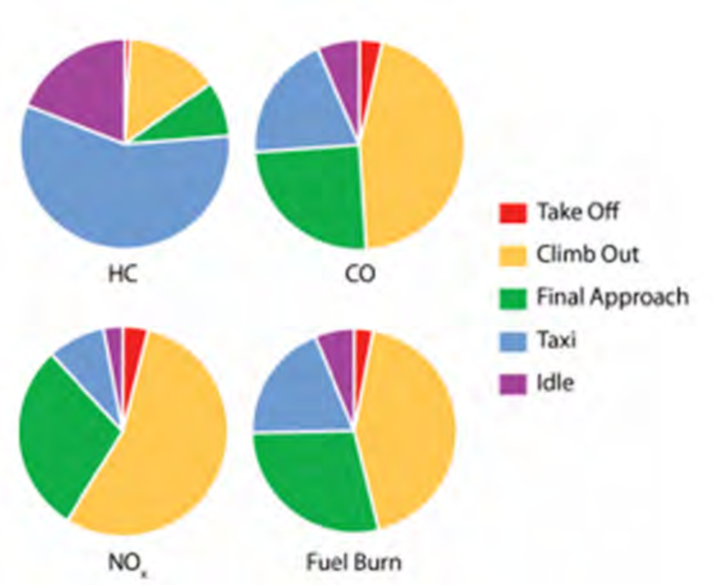

FIGURE 1-4 Partitioning of LTO emissions burden by power state for aircraft piston engines.[49]

1.2.2.1.2 Commercial Aircraft Thrust Settings

A number of recent studies looked at developing potential improvements to airport emission inventories through a better understanding of the role of engine thrust setting has on emissions. These studies sought to improve taxi/idle emissions,[56] climb-out, and approach fuel burn,[57] and takeoff emissions[58] with a focus on the actual thrust settings applied in an airport environment.[59,60] The improvements from these studies have been or can be incorporated into the FAA's AEDT model used for developing airport emission inventories.

1.2.2.1.3 Particulate Emissions from Commercial Aircraft Engines

Extensive research continues on particulate matter emissions from aircraft and airport operations. Aircraft particulates typically fall in the ultrafine size range that are even smaller than regulated PM_{10} and $PM_{2.5}$ and have a high potential to penetrate deep into the respiratory system. This is an important issue for aviation as ultrafine particulates are emitted at a high rate by aircraft engines. For ambient testing it is challenging to differentiate between aviation, on-road and other stationary combustion sources of ultrafine particulates. Aircraft exhaust measurements are conducted using both mass emission methods and particle counting methods.[61,62,63,64,65,66] In addition, particulate matter composition and shape has been studied to help identify the potential sources of non-volatile and volatile particulate matter formation in aircraft engines.[67,68,69,70,71]

1.2.2.1.4 Ground Support Equipment

Several ACRP studies looked at approaches to improve airport GSE data for estimating GSE emissions. One included surveys of a dozen airports across the United States to develop a nationwide count of GSE by type and fuel; and identified GSE emission reduction strategies.[72] Reduction strategies included the following:

- Converting to electric GSE and obtaining funding to do so,
- Gate electrification,
- In-ground hydrant fueling systems,
- Idling time restrictions, and
- Maintenance activities.

Another provided guidance on how GSE parameters, such as count by GSE type and GSE operating times per aircraft turnaround could be developed for a specific airport in support of a more accurate GSE emission inventory.[73]

1.2.2.2 Ambient Air Quality in the Vicinity of Airports

Over the last five to six years, a large number of measurement campaigns have been conducted on or near airports. By far, most have focused on particulate matter, reported as $PM_{2.5}$, black carbon, and/or ultrafine particulate matter (UFP) in the United States.[74,75,76,77] and in Europe.[78,79,80,81,82] Several studies provided information on measured concentrations of other pollutants such as total NO_x, NO_2, CO, and O_3.[83,84,85,86]

Several general conclusions reached regarding pollutant measurements and potential impacts to human health were discussed in *ACRP Research Report 135: Understanding Airport Air Quality and Public Health Studies Related to Airports*, and summarized below.[87]

- Airport contributions to gaseous criteria air pollutants (CO, NO_2, and SO_2) generally tend to be similar to background levels in surrounding communities.
- $PM_{2.5}$ levels have been found to vary significantly at different airports.
- Fine particulate concentrations often include a large fraction of secondary particles, those formed in the atmosphere from the emissions precursor compounds (NO_x, SO_x, and VOC to name several key precursors) which create fine particles far downwind of the emission sources. Estimating airport concentration contributions to fine particles often requires regional-scale modeling with programs that address atmospheric chemistry and physics.
- Measurement studies continue to indicate that airports are potentially important sources of ultrafine particulate matter.
- Potential health impacts from aviation activity is most likely dominated by fine, and possibly ultrafine, particulate matter. HAPs (or air toxics) also contribute to health impacts but to a lesser degree than particulates.

1.2.3 RESEARCH NEEDS

1.2.3.1 Fuels

The following research is needed to enhance the understanding of sustainable aviation fuels and air quality:

- SO_2 and sulfate emissions in aircraft exhaust are proportional to the fuel sulfur content (FSC) in conventional jet fuels. FSC in jet fuels has not been reduced to the levels of gasoline/diesel used in GAV. The benefit of employing low sulfur jet fuels on air quality and public health should continue to be investigated
- The benefits of sustainable aviation fuels (synthetic fuels and biofuels) in reducing the aircraft exhaust emissions through Commercial Aviation Alternative Fuels Initiative® (CAAFI®) should continue to be explored. Sustainable aviation fuels are low in aromatic content and sulfur free, which reduces PM emissions and its sulfur-based precursors
- Further examine any additional needed research based on ongoing research that is exploring ways to reduce or eliminate lead from AvGas used in GA operations

1.2.3.2 Engine Exhaust Plume Characteristics

The following research is needed to characterize engine exhaust plumes.

- Aircraft exhaust plume behavior has a significant impact on air quality in the vicinity of an airport. Barrett et al.[88] determined that not accounting for plume dynamics could result in over prediction of mean NO_x concentrations by a factor of 1.4 to 2.3. Plume dispersion processes and their impact on local air quality are not well understood. Airport air quality assessment models that are in use today (e.g., AEDT based on EPA's AERMOD,[89] ADMS-Airport,[90] and LASPORT[91]) do not adequately model aircraft plume dispersion. These models do not have the capability to accurately represent aircraft motion, plume rise, plume merger, and ground interaction of the aircraft exhaust plume. The plume characteristics employed in AEDT are based on Light Detection and Ranging (LIDAR) measurements of aircraft exhaust plumes made by Wayson et al.[92,93] Based on the analysis of the measurement data, they found the effect of aircraft type, temperature, wind speed, wind direction, and atmospheric stability are not statistically significant, and concluded that additional measurements would be required to determine the dependence of initial plume rise and dispersion on aircraft thrust, location of the engines and atmospheric stability. Measurements taken by Bennett et al.[94] showed that multiple plumes could emanate from the aircraft engine and could persist for a period of time. Presently, not much is known about the size and number of plume cores. In the right atmospheric conditions, aircraft plumes can be very persistent, and the vortices could last longer. The characteristics and behavior of plumes, the effect of meteorology on them, and the influence of the ground on plume behavior need to be better understood. Currently available mathematical models rely upon parameterization, which are poorly characterized. Aircraft exhaust plume measurements and their data analyses should lead to the development of distance-based or time-based aircraft engine exhaust plume rise algorithms for use in regulatory dispersion models.

- Given EPA's stringent 1-hour NO_2 NAAQS, studies on NO to NO_2 conversion mechanisms in aircraft exhaust plumes are warranted. The investigation by Wood et al.[95] led to the conclusion that NO_2/NO_x fraction is higher in advected plumes compared to the engine tests, and that a significant portion of the NO in the exhaust can be converted to NO_2 by mechanisms that do not involve ozone. Research studies are needed for studying the effect of switching from conventional to alterative jet fuels on NOx plume chemistry.

1.2.3.3 Other Airport-Related Sources

Air quality assessment of emissions from aviation sources for the local-/regional-scale analyses require comprehensive emissions inventories. Development of detailed inventories ensures that not only good emissions estimation methods are employed but also emissions from all non-aircraft sources are also accounted for. The following is a short list of research needs that would help improve local-/regional-scale air quality assessments.

- Guidance that provides a compilation of methods are needed for assessing emissions from non-aircraft sources unique to airports including those from GAV, GSE, engine run-up emissions, and PM emissions associated with brake and tire wear (depending on carbon brakes or use of reverse thrust). Sensitivity studies are needed to assess the effect of including/not including these sources on local air quality and the relative contributions from stationary and mobile source emissions. Research is also needed to study their effect on regulatory compliance and if they are pollutant dependent with special consideration to EPA's stringent 1-hour NO_2 NAAQS.
- Emissions increases from other sources due to increases in aircraft operations are not linear, in particular the GAV emissions. Research should explore such relationships, and thereby their impact on local air quality.
- Per *ACRP Research Report 164: Exhaust Emissions from In-Use General Aviation Aircraft*,[96] significant variability in emissions indices exists for the aircraft fleet at a GA airport and it is mainly due to variance of sub-models of those aircraft. Research is needed on increasing the confidence levels of the GA airport emissions inventories, especially for airports in nonattainment areas.
- Military aircraft emission impacts on local air quality, unlike civil aviation emissions impacts, are hard to assess mainly due to lack of comprehensive data on military aircraft operations and emissions indices. Research is needed to improve the existing environmental impact tools for estimating emissions accurately and assessing their air quality impacts reliably, especially for dual-use airports in urban and nonattainment areas where the air quality impacts could be significant.
- Airport emissions for the purposes of emissions inventories are compiled typically to a coarse resolution (tons per year units). Air quality models require the emissions to be spatially and temporally resolved, and therefore, these inventories do not meet air quality modeling needs. Airport air quality models, such as AEDT, address part of this concern by assigning the emissions generated by the aircraft operations spatially to an hourly resolution. For other sources, this burden is on the user; emissions, especially from GAVs, could affect local air quality near airports differently depending upon how they are resolved. Research is needed on spatial and temporal assignment methods of these emissions and their impacts on local air quality.

- Many of the recent studies discussed the geographical and vertical distributions of flights and concluded that the highest fuel burn and emissions occur at cruise altitudes and only 5 to 10 percent of fuel burn occurs below 1 kilometer. This means that only a small portion of the aircraft emissions that are emitted within the atmospheric mixing height due to LTO operations are a concern to air quality and health impacts in the vicinity of airports. Aircraft engine emissions have very little measurable impact on ambient air quality. Of these emissions, fine particulate matter has the largest health risk. A recent study[97] assessed the impacts of aircraft engine emissions on ambient $PM_{2.5}$ emissions using the Community Multiscale Air Quality (CMAQ) model and concluded that aircraft emissions increased annual average $PM_{2.5}$ concentrations only 0.0032 $\mu g/m^3$ (0.05%) in the continental United States. Particles emitted by the aircraft are mostly UFP (< 100 nm). Because concerns over the adverse health impacts of aircraft UFP emissions are increasing, the airport UFP emissions (both mass and number) should be reported as another pollutant in addition to $PM_{2.5}$. There are no studies describing the health effects of UFPs around airports.[98] Therefore, studies investigating the health effects of aircraft UFP in the vicinity of airports are highly desired.
- A secondary concern from aircraft emissions is the contrail formation at cruise altitudes, which do not pose a direct threat to the public health. The key factors that affect contrail formation and evolution include aircraft technologies, spatial and temporal distribution of aircraft traffic, and atmospheric relative humidity. Contrail geographic and frequency of coverage could be affected by changes in the fuel efficiency of the engine, while changes in air traffic might affect the persistence of contrails. Studies are needed for investigating such effects on contrail coverage and persistence.
- Aircraft NO_x emissions ($NO + NO_2$) increase as a function of engine thrust. NO_2/NO_x ratio is inversely proportional to the thrust and may vary between 75 to 98 percent at low thrust and for approach may vary between 12 to 20 percent.[99,100] NO reacts with ambient ozone and forms NO_2, and NO_2 is of health concern and is one of the six criteria pollutants. EPA promulgated the 1-hour NO_2 NAAQS in 2010 in addition to the existing annual NO_2 NAAQS. Therefore, high 1-hour concentrations of NO_2 is a concern for air quality near major airports. A number of airport modeling studies can be found that modeled an airport for inter comparison of different airport air quality models.[101] Carruthers et al.[102] made such a model comparison for annual average NO_x predictions with ADMS-Airport, LASPORT, and EDMS, and attributed ADMS-Airport's good performance to the treatment of plume buoyancy and dispersion for jet aircraft exhaust plumes. Tetra Tech's[103] evaluation of EDMS-AERMOD for Los Angeles International Airport (LAX) Air Quality and Source Apportionment Study reported a varying model performance from fair to poor. This poor performance is attributed to shorter averaging times at LAX, complex terrain at the site, land-/sea-breeze effects, greater frequency of unstable conditions, and the neglect of plume rise for the aircraft sources. The EPA's approach to modeling hourly NO_2 impacts with AERMOD is only a screening method and does not account for photolysis of NO_2, which is relevant for ambient impacts assessments. Further, research should be conducted to develop and evaluate explicit NO_x chemistry methods needed for 1-hour NO_2 modeling at airports. NO_2/NO_x ratio is inversely proportional to the thrust, and is significant during aircraft idling operations; research is needed for assessing the hourly NO_2 ambient impacts in the vicinity of airports. Research is also needed to study the feasibility of hybrid modeling approaches (e.g., AERMOD with CMAQ) for estimating NO_2 concentrations.
- Best practice guidance exists in FAA Order 1050.1F for air quality environmental review of projects related to federal actions in nonattainment areas for quantifying and disclosing

air quality impacts. Typically, significant air quality impacts would be identified if a federal action results in exceedance of a NAAQS. CAA - Section 176(c) requires federal actions conform to the applicable SIP so that the proposed project will not violate the NAAQS, worsen existing violations, or delay attainment of the NAAQS. Part of the FAA Order 1050.1F guidance indicates further air quality analysis for NEPA is not required if the federal action emissions do not exceed EPA's de minimis emissions thresholds. Currently such NEPA guidance is not available for air quality review of federal actions in attainment areas. As a result, some practitioners may be applying nonattainment best practice guidance to federal actions in attainment areas. Most airports (greater than 85 percent) reside in attainment areas that have ambient concentrations of criteria pollutants well below the NAAQS levels, except for a handful of airports that may be close to the NAAQS. Therefore, most of the projects at these airports do not contribute to the violation of a NAAQS. Clear guidance for environmental review of air quality impacts for federal actions in attainment areas is needed so that the appropriate effort can be made toward reaching a significance determination

NOTES

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1.3
Climate Change

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1.3.1 INTRODUCTION

It is the overwhelming consensus within the scientific community that the observed global warming and attendant climate change is driven by the increase in GHG emissions into the atmosphere from anthropogenic activities, such as combustion of fossil fuels from energy production and transportation. The primary GHG, aside from water vapor, is carbon dioxide (CO_2), with methane (CH_4) being the next most intensive gas in global warming potential. Current global atmospheric concentrations of CO_2 total 411 ppm,[104] a level last reached over 3 million years ago (**FIGURE 1-5**).[105] The rise in CO_2 emissions has coincided with a rise in global mean surface temperatures, which are currently 1º Celsius (C), or 1.8º Fahrenheit (F), higher than in 1880 (see **FIGURE 1-6**),[106] and global surface temperatures are increasing by approximately 0.2º C per decade).[107] The increase in atmospheric CO_2 has also coincided with a rise in global sea levels, which are currently 7 to 8 inches higher than in 1900.[108] Absent significant reductions in GHG emissions, global temperatures are predicted to increase by 5º C (9º F) by 2100 while rising sea levels are expected to continue.[109] Ocean temperature and acidity are also rising due to higher levels of atmospheric CO_2 absorbed by the oceans.[110] These changes will lead to unpredictable, dangerous, and permanent impacts to humans and the natural environment.

Aviation's contribution to CO_2 emissions from fuel burn is relatively well understood and estimated to be approximately 2 to 3 percent of the annual global total.[111] In addition to CO_2, aircraft engines emit water vapor, hydrocarbons (HC), NO_x, sulfur oxides (SO_x), CO, and black carbon (soot). The complex interactions between these emissions and the atmosphere have been studied for years, and it is well understood that some of these emitted gases and particles contribute to positive radiative forcing or warming effect (i.e., the difference between the amount of energy coming into Earth's atmosphere from the sun and the energy that is reflected back out of the atmosphere), as do persistent contrails produced by aircraft.[112] Other interactions and indirect effects of aviation lead to warming and cooling of the climate (i.e., sulfates have a negative radiative forcing or cooling effect).[113] In contrast to the long-lived CO_2 emissions, impacts of these other emissions and interactions are short lived and therefore are known as non-CO_2 short lived climate forcers.

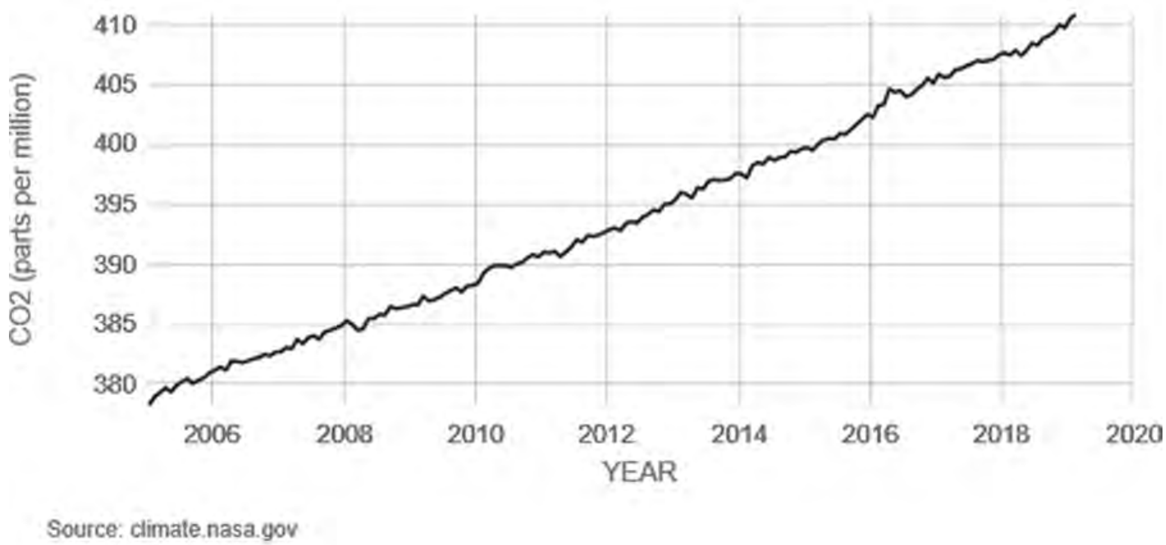


FIGURE 1-5 Direct CO_2 measurements: 2005–present.

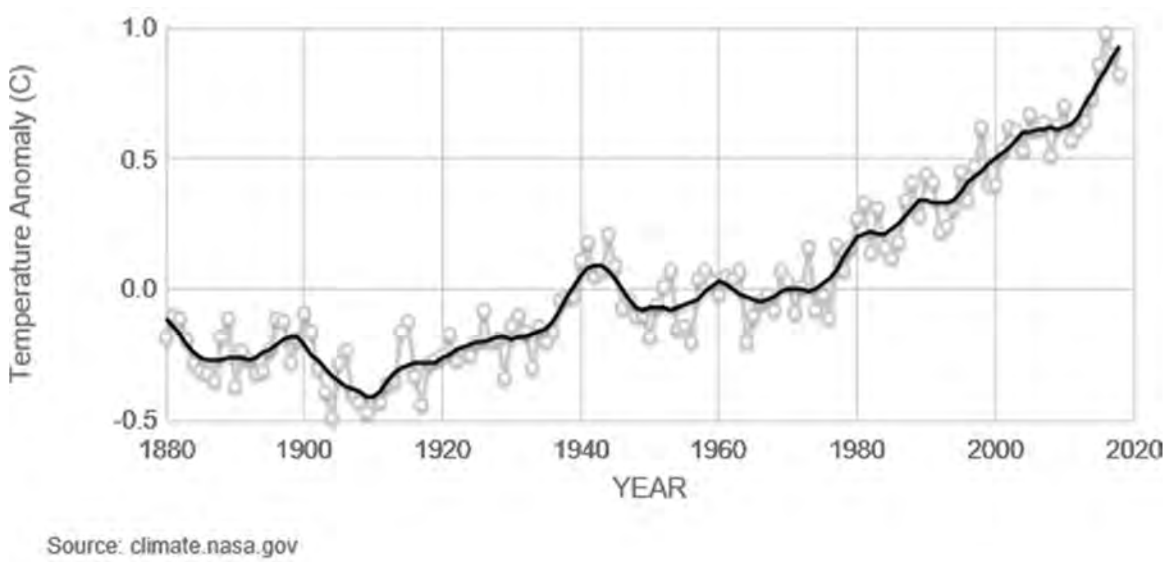


FIGURE 1-6 Global land-ocean temperature index.

Transportation accounts for 23 percent of all anthropogenic GHG emissions; **FIGURE 1-7** illustrates direct GHG emissions of the transport sector (shown by mode) rose 250 percent from 2.8 gross ton (Gt) CO_2 equivalent (CO2eq) worldwide in 1970 to 7.0 Gt CO2eq in 2010.[114] Collectively, CO_2 and non-CO_2 emissions from aviation represent approximately 4 percent of the global total radiative forcing (RF) from anthropogenic sources.[115] Radiative forcing is the difference between incoming and outgoing radiation in a planet's atmosphere. When incoming energy is greater than outgoing energy, it causes a climate forcing effect of warming.[116] An additional factor unique to aviation is that most of its emissions are produced at cruise altitude, within the upper troposphere and lower stratosphere,[117] which is a sensitive region for atmospheric processes. These effects have been the subject of prior research from the FAA sponsored Aviation Climate Change Research Initiative (ACCRI), and the FAA Centers of Excellence for aviation environmental research, including ASCENT and its predecessor, Partnership for Aviation Noise and Emissions Reduction.[118] This is described in the following sections on the current state of research and practice. Understanding these impacts is critical, as the FAA anticipates a 2.2 percent worldwide annual growth rate in the aviation industry over the next 20 years in terms of revenue passenger miles.[119] In addition, ICAO anticipates the global demand for aviation fuel use to grow by 2.8 to 3.9 times between 2010 and 2040.[120]

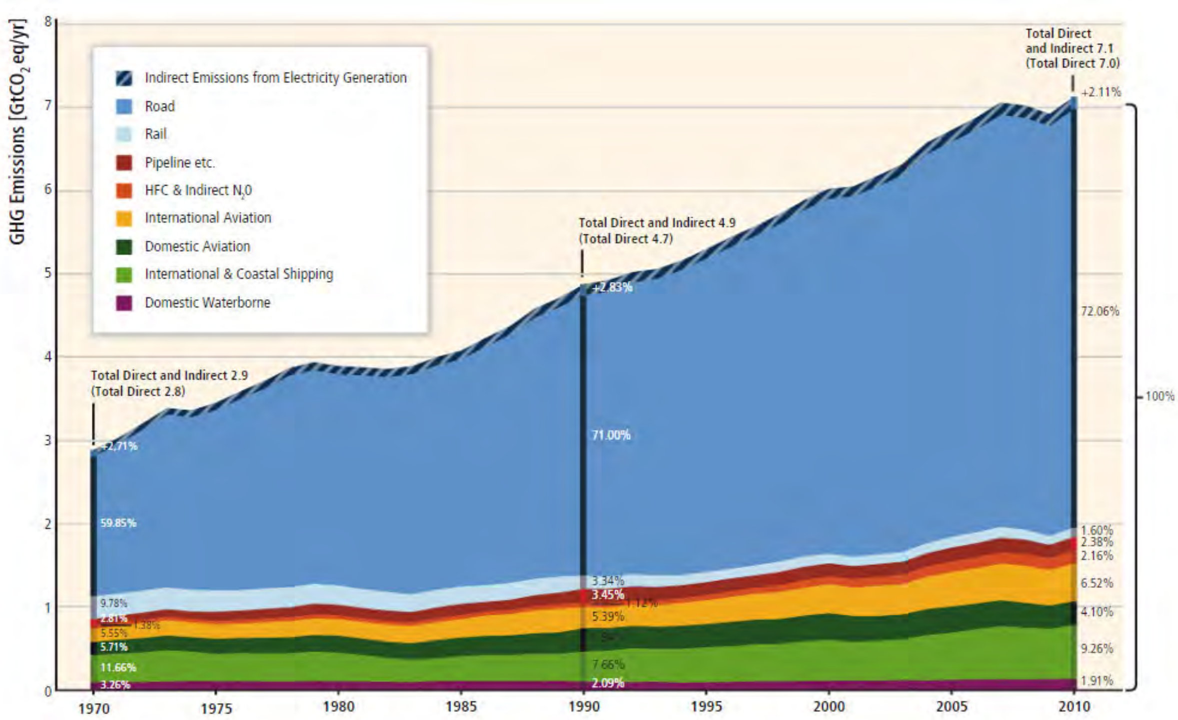


FIGURE 1-7 Direct GHG emissions of the transport sector.[121]

1.3.2 CURRENT STATE

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 from aircraft non-CO_2 emissions (i.e., NO_x, SO_x, and particulate matter) have relatively higher uncertainties compared to those of CO_2 impacts. Additionally, the Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report describes scientific understanding of climate forcing due to contrails and induced cirrus clouds as 'low' to 'very low' level.[122] This 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.[123]

There are atmospheric feedbacks and interactions that have the potential to modify aviation non-CO_2 climate impacts. This was part of the principal basis of the creation of the FAA sponsored ACCRI that completed its Phase II activities in 2014.[124] ACCRI also focused on defining and analyzing options for metrics for aviation climate impacts. **FIGURE 1-8** 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 [APMT]) (ASCENT Project 58).

FIGURE 1-9 provides ACCRI estimates of certain components of aviation impacts that were previously reported by Lee et al. (2009).[125] Aircraft CO_2 emissions contribute nearly 37 percent 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 increased 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 cloud 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) but is highly uncertain and underlying mechanisms still need to be well understood.

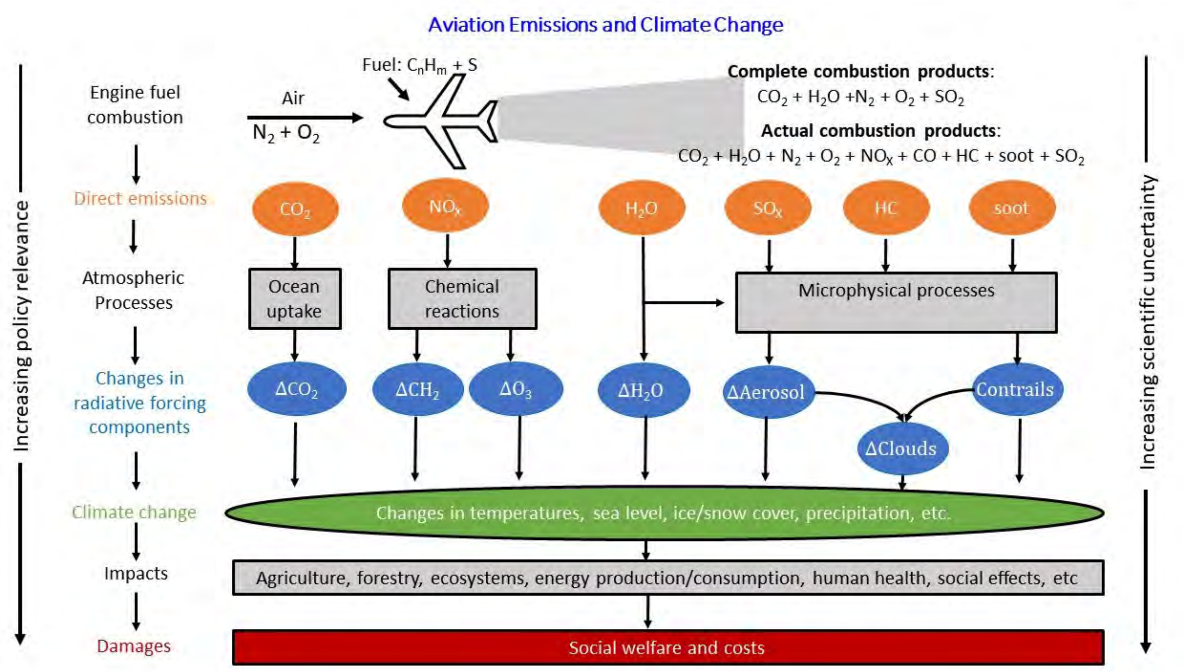
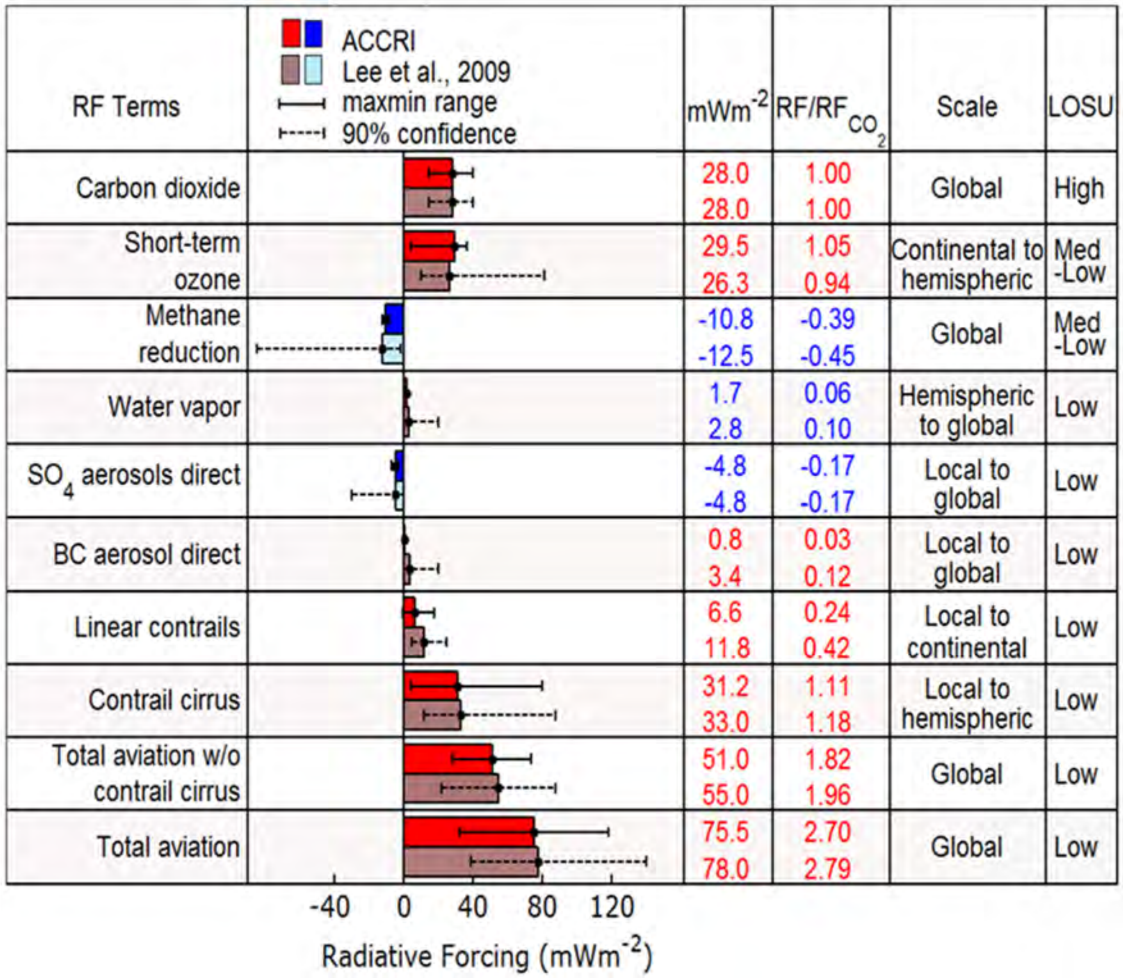


FIGURE 1-8 Schematic flow that links aircraft emissions to their contributions to climate change.[126]

The ACCRI Consortium also focused on future climate impacts for 2050 for baseline and mitigation-based aircraft emissions scenarios that included a 2 percent per year increase in fleet-wide fuel efficiency due to combined advances in aircraft technologies and environmentally efficient operational procedures as well as introduction of 50 percent blended renewable 'drop-in' alternative jet fuels. Combustion of renewable fuels is inherently low in black carbon emissions, and 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 sustainable aviation 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. Chapter 2 includes sustainable solutions to help address many of these concerns.



Notes: ACCRI results comprising global radiative forcing components, spatial extent, and level of scientific uncertainty are shown here for the various components for the year 2006. Total radiative forcing in the last two rows is a sum of all individual radiative forces without and with contrail cirrus radiative forcing, respectively. Contrail cirrus radiative forcing also includes linear contrail radiative forcing, which has been subtracted from total aviation radiative forcing 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 radiative forcing for each effect. The values of the minimum and maximum are summed to provide the minimum and maximum, respectively, in the total values.[127]

FIGURE 1-9 ACCRI results comprising global radiative forcing components, spatial extent, and level of scientific uncertainty.

The introduction of ‘drop-in’ renewable (non-petroleum based) alternative jet fuels, which are devoid of sulfur emissions during combustion, can reduce CO_2 emissions during the entire life cycle process but could also reduce emissions of non-volatile black carbon (nvPM). In addition to reducing direct radiative forcing, decreases in direct emissions of particulate matter 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. The ASTM has already approved the use of seven alternative, bio-based jet fuels[128, 129] including:

- Alcohol to Jet Synthetic Paraffinic Kerosene, created from isobutanol derived from sugar, corn and wood waste products;
- Synthesized Iso-paraffins, converts sugar to jet fuel;
- Hydroprocessed Esters and Fatty Acids (HEFA) Synthetic Paraffinic Kerosene), made from fats, oil and grease;
- Fischer-Tropsch Synthetic Paraffinic Kerosene;
- Fisher-Tropsch Synthetic Kerosene with Aromatics (both Fisher-Tropsch Synthetic Kerosene with Aromatics and Fisher-Tropsch Synthetic Kerosene with Aromatics with Aromatics use biomass such as woody biomass and municipal solid waste);
- Catalytic Hydrothermolysis Jet using waste oils; and
- Synthesized paraffinic kerosene from hydrocarbon-hydroprocessed esters and fatty acids.

The FAA set an aspirational goal of annual use of 1 billion gallons of alternative jet fuel by U.S. aviation by 2018.[130] Likewise, Flightpath 2050: Europe's Vision for Aviation calls for deployment of 2 million tons of sustainable biofuels by European Union (EU) aviation by 2020.[131] Despite these goals, the increase in approved sustainable aviation fuel production pathways and successful flights with biofuel blends, only about 1.2 million gallons of alternative jet fuel are produced each year in the United States. According to CAAFI®, the production potential will not reach 250 million gallons annually for another five years (2024).[132]

Next generation air traffic and airspace management programs such as NextGen[133] and the EU Single European Sky Air traffic management Research (SESAR)[134] are programs to modernize the airspace by transforming the efficiency, safety and mobility of the aviation system, however they also provide environmental protection through satellite and digital technology-driven aircraft routing. Advances in gate-to-gate (surface and en route) operational procedures through initiatives such as the Atlantic Interoperability Initiative to Reduce Emissions[135] have demonstrated significant environmental and fuel burn benefits.

Despite the potential emissions and fuel burn benefits from the implementation of NextGen technologies, airspace redesign efforts (particularly those involving performance based navigation or procedures) have caused significant community concerns due to concentration of noise impacts into narrow corridors. This has resulted in public opposition to continued implementation of Metroplex projects (Metroplex is the term used for optimization of the airspace around several airports in major metropolitan areas). The schedule for future implementation of Metroplex for some of these technologies has been therefore delayed.[136]

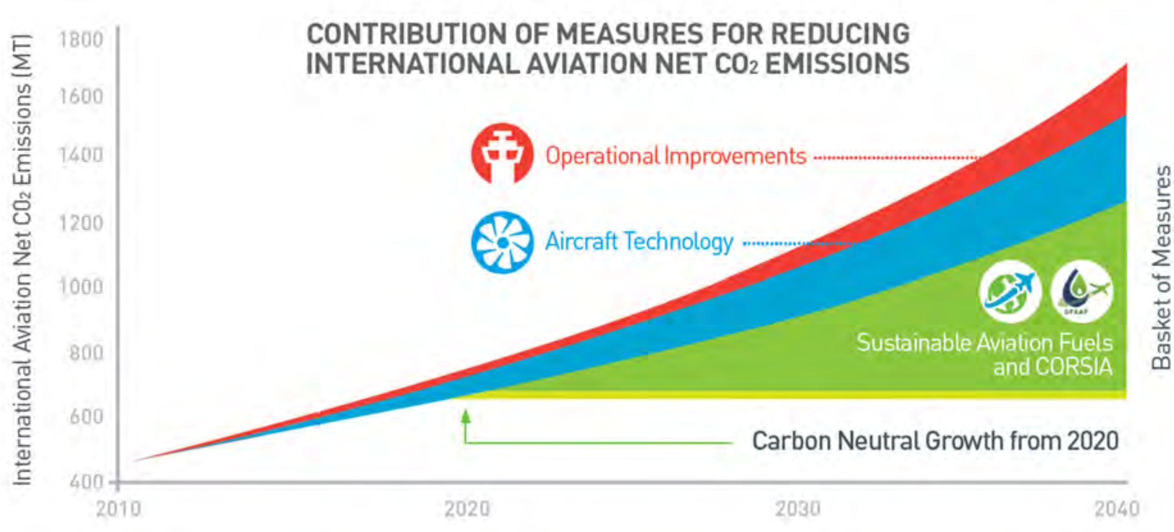
Policy measures, such as goals to achieve carbon neutral growth and fuel efficiency as well as internationally accepted environmental standards, can contribute to emissions reduction. This section briefly reviews legislative and policy developments regarding CO_2 emissions from aviation and means of reducing climate impacts of other aviation emissions (e.g., NO_x or 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 (UNFCCC).[137] This committed signatories from developed nations and the EU to an average target of a 5 percent 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 mandated a second commitment period for the Kyoto Protocol to January 1, 2020.[138]

There have been several Conferences of Parties (COP) meetings of the UNFCCC since the Kyoto Protocol. At the 21st COP in 2015, the Parties reached an agreement to limit global warming to less than 2°C above pre-industrial levels, known as the Paris Agreement. The Paris Agreement requires signatories to take actions to meet the goal and to set nationally determined contributions. Nationally determined contributions are measures that states plan to reduce emissions to meet the 2° goal and to adapt to climate change, which differ based on national capabilities. While domestic aviation GHG emissions are covered by the Paris Agreement, emissions from international aviation are the purview of ICAO.[139] While 185 states have ratified the Paris Agreement to date, the United States withdrew from this agreement in 2019. Although the United States formally withdrew from the Paris Agreement, 24 states and hundreds of cities and corporations have voluntarily committed to meeting Paris Agreement targets.[140, 141]

ICAO member states have been working for several years to address international aviation's GHG emissions and in 2013 agreed on a goal of carbon neutral growth from 2020 onward.[142] **FIGURE 1-10** shows how measures to reduce emissions could help achieve this goal. As a result, ICAO has developed and approved both an Aircraft CO_2 Emissions Standard, and a global market-based measure, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), to reduce GHG emissions from international aviation.

ICAO's CAEP agreed on a metric system for the Aircraft CO_2 Emissions Standard in July 2012 (which was approved by the ICAO Council in 2013), and the full ICAO Assembly adopted the Emissions Standard in 2016.[143,144] ICAO member states must write implementing regulations to integrate the Standard into their own regulatory framework. The Emissions Standard applies to new aircraft type designs starting in 2020, and to aircraft type designs already in production starting in 2023. In-production aircraft have until 2028 to comply, after which they will not be able to be produced.[145]

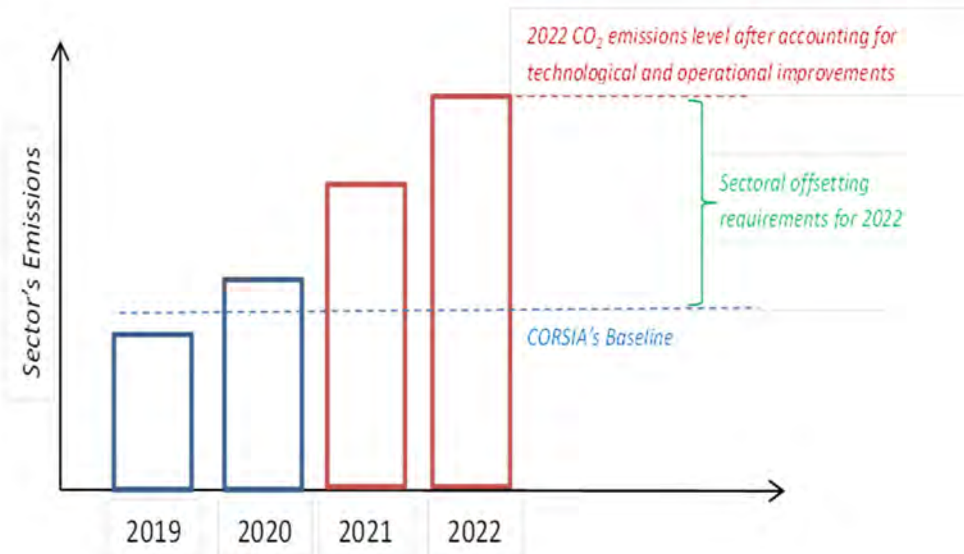


Source: ICAO

FIGURE 1-10 Pathway to carbon neutral growth.

ICAO also approved CORSIA, a market-based measure to reduce international aviation's CO_2 emissions at the 39th ICAO Assembly in 2016.[146] CORSIA requires all aircraft operators who emit more than 10,000 tons of CO_2 emissions on international flights to monitor, report, and verify their GHG emissions from international flights and offset all emissions over the operator's baseline emission. The baseline is the average sectoral CO_2 emissions from years 2019 and 2020

(**Figure 1-11**). Operators falling within the scope of applicability of CORSIA will have their offsetting requirements calculated through a combination of their individual emissions as well as a sectoral growth factor.[147]



Source: ICAO

Figure 1-11 CORSIA offsetting requirements.

CORSIA is being implemented in three phases. The Pilot Phase (2021-2023) and First Phase (2024-2026) are voluntary, and the Second Phase (2027-2035) is mandatory for all eligible states.[148] The voluntary phases are occurring through 2027, after which time all operators falling within the scope of applicability of CORSIA from participating countries will need to offset their emissions over their baseline levels. 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.[149]

To address air quality impacts and non-CO_2 climate impacts, CAEP periodically approves more stringent NO_x engine emissions standard, the last of which was in February 2010. In February 2019, CAEP approved to an inaugural emissions standard for nvPM emissions from aircraft engines.[150] This nvPM standard will lead to reduction in climate impacts due to black carbon emissions.

1.3.3 RESEARCH NEEDS

The following research is needed to enhance the understanding of the aviation industry's impact on climate change.

- 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 NOx, indirect aerosol, and contrails-induced cirrus 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 CO2 and non-CO2 aviation impacts to support policy analysis needs.
- Refinement of current models that translate changes in radiative forcing from various aviation mechanisms to changes in surface temperature. Specifically, studies and simulations to examine the effects of short-lived non-uniform radiative forcing versus long-lived and uniform radiative forcing on surface temperatures.
- Research on the indirect effect of aviation aerosols on clouds and other indirect effects of aviation on climate.
- 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 inform aviation cost-benefit analysis (note, this research would not be unique to aviation).

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1.4
Water Quality

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1.4.1 INTRODUCTION

Over the past several decades, interest and concern over the potential water quality impacts of a range of airport operations has increased. Airport stormwater quality issues generally focus on total suspended solids, oil and grease, and pH, and then depending on the level of deicing or other activities, also Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). Environmental regulators also 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 emerging legacy pollutants, attenuation of peak stormwater flows, erosion and sedimentation, and non-point source runoff. Airports typically include large areas of impervious surface and host activities that can generate discharges of potential contaminants, such as vehicle and aircraft fueling, maintenance, deicing, and firefighting chemicals. While airports have been subject to the requirements of the Clean Water Act (CWA) for almost three decades, the application of these rules to the unique operating environment of airports continues to be refined.

In recent years, new developments and issues have emerged in the areas of deicing, stormwater management, and emerging pollutants. These include the following:

- The aviation industry successfully completed a Voluntary Pollution Reduction Program aimed at reducing discharges of aircraft deicers on a national basis
- Advancements in aircraft deicing technologies have significantly reduced the volumes of glycol required to deice aircraft under milder wintertime conditions

- Issues surrounding the compatibility of "environmentally-friendly" airfield pavement deicers with aircraft and airfield infrastructure continued to be explored
- Changes in design storms based on the adoption of newer and more complete precipitation records nationwide
- The increased development of guidance manuals to focus on airport-specific requirements for stormwater best management practices (BMP) with an understanding of safety requirements relative to wildlife attractants
- The need to meet increasingly stringent stormwater management requirements beyond those associated with FAA design guidelines
- Incorporation of stormwater management into sustainability goals at airports
- The emergence of a focus at airports on the use of Green Infrastructure and Low-Impact Development techniques to manage stormwater close to the source as part of nature-based solutions
- Airports around the nation began to be drawn into concerns regarding contamination of drinking water supplies and surface waters by per- and polyfluoroalkyl substances (PFAS) that are currently required components of aqueous film-forming foam (AFFF) products used by aircraft rescue and firefighting operations and aircraft hangar fire suppression systems

1.4.2 CURRENT STATE

1.4.2.1 Issues Surrounding Aircraft and Airfield Deicers and the Environment

Managing the environmental impacts of runoff from aircraft and airfield pavement deicing operations is one of the most significant water quality issues that most northern tier airports face. The original compliance requirements associated with the CWA's National Pollutant Discharge Elimination System (NPDES) stormwater permit program were implemented in the 1990s. Since that time, NPDES permits authorizing discharges of stormwater containing deicers have been issued to virtually all airports with deicing operations. Over time, many airports have significantly expanded or revised their original management controls to achieve even higher levels of efficiency and performance in reducing discharges of deicers to the environment compared to regulatory requirements. Current developments in this area are incremental, reflecting the generally mature state of the industry.

1.4.2.1.1 Aircraft Deicing Technology Developments

The most significant developments in aircraft deicing have been in commercialized technologies that reduce the volumes of glycol required to deice aircraft and ensure the safety of winter flight operations. Two strategies are primarily responsible for achieving reductions: (1) blending to temperature (BTT) and (2) force air/fluid deicing. Both of these apply only to the application of Type I aircraft deicing fluids (ADF).

BTT technology facilitates the use of the lowest safe ADF concentrate to water mixture under ambient temperature conditions. ADF is produced in concentrated form and then diluted with water prior to application. The dilution mixture required to meet FAA criteria varies with outside air temperature (OAT), and dilution charts describe the lowest OAT for a range of ADF mixtures. Lower concentrations are acceptable at higher OATs. Traditionally, aircraft operators adopted the conservative approach of using a standard ADF mixture, typically between 45:55 and 63:37, throughout the deicing season to ensure consistent compliance with FAA criteria under the full range of anticipated OATs at an airport. In addition, there were practicality and safety concerns to changing the applied mixture over the course of aircraft operations. BTT technology makes it both easier and more reliable to adjust the ADF mixture over short timeframes. The technology takes several forms, from centralized blending stations that adjust the mixture loaded in a deicing truck's tanks based on anticipated temperatures that will be encountered, to automated blending systems on deicing trucks that can adjust the dilution "on the fly." Reductions in ADF concentrate usage of up to 45 percent may be possible, depending heavily on the range of OATs encountered at an airport over a deicing season. The reductions will be less at airports that experience consistently lower temperatures during the winter than at airports with more temperate winter conditions.

Forced air/fluid technology reduces and, in some instances, eliminates the volume of ADF required initially to deice an aircraft by using a high-velocity stream of air to mechanically dislodge and remove snow and ice. A low flow stream of ADF is typically available to aid in breaking loose snow and ice attached to aircraft surfaces. Forced air/fluid deicing trucks employ specialized equipment that delivers high-pressure air and controlled Type I ADF mixtures to the aircraft surface. Some trucks are also capable of using air in applying Type IV anti-icing fluids that protect the aircraft during taxiing and takeoff. While performance varies by airport due to many competing variables, reductions by as much as 45 to 65 percent in seasonal ADF usage have been reported, with the greatest effectiveness observed under dry/powdery snow conditions and the least in removing ice bonded to aircraft surfaces.

Both technologies are described in *ACRP Research Report 14: Deicing Planning Guidelines and Practices for Stormwater Management Systems*.[151]

1.4.2.1.2 Issues with Airfield Pavement Deicers

For many years, airport stormwater pollution prevention focused more on aircraft deicing than airfield pavement operations because the ingredients in aircraft deicers cause significantly more dissolved oxygen depletion and aquatic toxicity. With recent advances in BMPs in collection and treatment systems for aircraft deicing, more attention is turning to pavement deicing. One ACRP project currently underway is 02-87 to provide guidance for evaluating airfield pavement deicer contributions to stormwater quality. In 2020, TRB published *ACRP Research Report 14: Guidebook and Decision Tool for Managing Airport Stormwater Containing Deicers, second edition*, an update from the first edition published in 2009, addressing new BMPs and standards for wastewater discharged from airports.[152]

Compared to aircraft deicers, pavement deicer chemistry has remained relatively unchanged. The one exception is that the EPA has essentially banned the use of urea by mandating cost-prohibitive collection and treatment mandates related to its use through its 2012 Airport Effluent Limitations Guidelines rulemaking. And unlike aircraft deicers, which are generally cryoprotectants (materials that prevent liquid water from freezing, but are relatively ineffective at melting existing ice), pavement deicers cannot use heat to melt or thickeners to create a slippery protective film. Their performance instead must depend on their inherent ability to melt ice and actively maintain friction at low temperatures. This critical difference limits the available chemistries for the development of new pavement deicers. Hence, they generally fall under a family of chemicals known as alkali-organic salts (e.g., sodium- or potassium- acetates and/or formates). As a result, most new developments in pavement deicers are hybrids where traditional acetate/formate deicers are blended with polyol cryoprotectants (e.g., glycol or glycerin). These hybrid deicers are generally intended to mitigate specific issues such as electrical conductivity or degradation of carbon brakes from alkali catalytic oxidation.

The alkali metals, potassium, and to a lesser extent, sodium, have been identified as catalysts that, when combined with the heat generated during braking, can attack carbon brake materials. The catalytic brake oxidation problem can be exacerbated by the increased thermal load caused by heavier braking that accompanies recent air traffic control practices implemented to mitigate other airport issues (e.g., directing aircraft to take the first available taxiway to increase number of landings per hour, or prohibiting the use of reverse thrust—especially at night—to assist with noise abatement). The hybrid deicers contain a reduced amount of alkali catalyst and testing has shown significantly reduced carbon brake degradation. Unfortunately, these deicers have a higher BOD than conventional acetates/formates, have higher low-temperature viscosities which may reduce friction, and are often more expensive due to raw material costs.

Regardless of the deicer used, all airports can benefit from the current trend of focusing on methods to reduce the amount of chemical needed to maintain safe friction levels (e.g., anti-icing with a reduced amount of chemical deicer to prevent the bond between the ice and pavement so that subsequent plowing/brooming is more effective, as opposed to deicing after ice has been allowed to adhere). Airport winter operations managers are encouraged to continue to learn about these and other issues and best practices.

1.4.2.1.3 Industry-Led Voluntary Pollution Reduction Program

In 2012, Airlines for America, Airports Council International-North America (ACI-NA), the Regional Airline Association, and the American Association of Airport Executives announced the launch of the Voluntary Pollution Reduction Program (VPRP) to promote and document industry efforts to reduce the discharge of ADF to the environment.

The VPRP was implemented over a five-year period from September 2012 through September 2017. During that period, the program promoted and facilitated the exchange of information about aircraft deicing-related pollution reduction technologies and practices through outreach, industry events, and ACRP participation. To quantify the effectiveness of these and other industry efforts, the concept of “BOD Management Capacity” and a corresponding metric, the “BOD Management Capacity Index” were developed. The national aggregate BOD Management Capacity Index was calculated for a set of 42 airports that represent approximately 83 percent of total national ADF usage. The goal for the VPRP was to achieve a 20 percent improvement in the national index between January 1, 2005 and September 30, 2017.

A final report was published in March 2018 to document the full range of VPRP activities and provide a final quantitative assessment of the industry’s progress in reducing pollution associated with aircraft deicing activities as reflected by the BOD Management Capacity Index. The analysis determined that the national BOD Management Capacity Index value had improved by 36 percent over the 2005-2017 Program Period, exceeding the original 20 percent improvement goal.[153]

1.4.2.2 Stormwater Management

Airport stormwater quality continues to focus on basic contaminants such as total suspended solids (TSS), oil and grease, and pH, as well as various other contaminants related to deicing or other pollutant-generating activities conducted at airports that impact stormwater. Different pollutant sources may be regulated in different ways or under different programs.

1.4.2.3 Regulatory Developments

1.4.2.3.1 Municipal Separate Storm Sewer Systems

Stormwater from urban streets and municipal separate storm sewer systems (MS4) is a significant source of pollutants discharged to waters of the United States. Urban stormwater can impact surface water resources by modifying natural flow patterns or by elevating pollution concentrations and loadings.

Congress passed the 1987 CWA amendments directing the EPA to establish phased NPDES requirements for MS4 discharges. The EPA’s 1990 Phase I MS4 stormwater program required permits for discharges from medium and large MS4s serving a population of 100,000 or more. The EPA’s 1999 Phase II program expanded the MS4 permit requirements to include small MS4s in certain urbanized areas and for certain “non-traditional” MS4s, including many airports. By statute, MS4 permits must control pollutant sources to the “maximum extent practicable.” Airports that operate wholly within a medium or large MS4 may be required to comply with that MS4’s permit mandates if they discharge stormwater into that MS4’s stormwater collection and conveyance system.

One ongoing dispute currently being litigated is whether the EPA has the authority to mandate that state and/or local authorities regulate post construction stormwater discharges, which essentially results in regulating the amount of impervious surface associated with any new or redevelopment projects, through MS4 stormwater permit programs. Such projects are common at airports and usually include significant amounts of impervious surface. Questions regarding the EPA’s authority to mandate stormwater infiltration or otherwise regulate stormwater flow related to completed construction projects into perpetuity are part of multi-party litigation over the Massachusetts and New Hampshire MS4 permits issued by EPA Region 1 (these are two of the four states remaining in which the EPA issues NPDES permits for the state). The cases are currently in mediation. Ultimately, the cases could decide whether the EPA can include such mandates in other MS4 permits. The EPA initially sought to control post construction stormwater discharges through a stand-alone program but abandoned that effort due to being too costly. Alternatively, the EPA could delegate to states and/or localities to implement more site-specific and flexible permit terms to achieve local environmental protection goals, as appropriate.

These are particularly important issues for airports even though many have developed good working relationships with their state and local permitting authorities. Airports may have little input or influence if the EPA can independently mandate that state and local authorities implement inflexible stormwater retention standards that might require separate stormwater storage capability either above ground (i.e., retention ponds that could attract birds/other wildlife) or underground (i.e., vaults or drainage systems that are expensive and could present structural concerns).

1.4.2.3.2 Industrial Stormwater

To minimize the impact of stormwater discharges from industrial facilities, the NPDES program includes a stormwater permitting component specific to various categories of industrial activities from sites that discharge industrial stormwater to an MS4 or directly to waters of the United States. The EPA and most NPDES-authorized states choose to issue general permits to regulate these stormwater discharges when possible. The EPA's industrial general permit, the Multi-Sector General Permit or MSGP, includes industry-specific "chapters" that describe compliance requirements tailored to activities in each industrial sector. The requirements only apply to areas within a facility where the sector-specific activities occur. Most states use EPA's MSGP as a model for their state general permits.

Air transportation is one of the categories that the EPA identifies as generating "stormwater associated with industrial activity" and requires discharges be authorized under an NPDES industrial stormwater permit. Air transportation is addressed in "Sector S" of EPA's MSGP and contains requirements that apply to stormwater discharges from those portions of an airport where vehicle maintenance, equipment cleaning operations, or deicing operations are conducted. Refer to 40 CFR § 122.26(b)(14) for a definition of stormwater discharge associated with industrial activity. Under this Sector, certain airports must collect representative samples whose average results must be below certain EPA pollutant "benchmarks," or the airport must take corrective action to further reduce the pollutant in question.

EPA's most recent version of the MSGP was promulgated in 2015 and was subsequently challenged by several environmental groups. The EPA settled those cases and agreed to allow the National Academies of Sciences to conduct a study of various controversial aspects of the MSGP, including:

1. To review existing literature and the MSGP's current benchmark monitoring requirements and evaluate whether there are any improvements in benchmark monitoring to allow the EPA to evaluate the performance of industrial activity-related stormwater control measures (SCM). If so, suggest improvements or alternatives to the EPA's use of benchmark monitoring to best reflect appropriate technology and water quality related BMPs for industrial stormwater.
2. To evaluate the feasibility (and defensibility) of numeric stormwater retention standards (e.g., volumetric control standards for a percent storm size or based on percentage of imperviousness) for industrial stormwater dischargers, or specific sectors of industrial stormwater dischargers, as appropriate, and make recommendations regarding the availability of data and the appropriate statistical methods for establishing such standards as both technology-based and water quality-based numeric effluent limitations.
3. To consider how the EPA could identify the highest priority industrial facilities or subsectors for consideration of additional discharge characterization and/or monitoring. By the term "highest priority," the research should consider the facilities/subsectors for which the development of numeric effluent limitations or reasonably uniform or standardized SCMs would be most technically and scientifically defensible, based upon sampling data, data gaps and the likelihood of filling them, statistical issues such as the variability that exists at well-operated sites, and data quantity and quality issues that may impede the calculation of numeric limitations.

The National Academies of Sciences, Medicine, and Engineering completed its study in February 2019.[154] In the interim, the EPA also is working to revise its industry- (or sector-) specific BMP guidance manuals, including its Air Transportation BMP guidance document. The new MSGP (MSGP 2021) was issued by EPA on January 15, 2021, with an effective date of March 1, 2021.[155]

1.4.2.3.3 Construction Stormwater

The EPA and most NPDES-authorized states have issued NPDES general stormwater permits for discharges associated with construction activity (typically called "construction general permits" or "CGPs") that are separate from the industrial stormwater general permits. This distinction is due to the unique issues associated with temporary active construction operations that disturb soils. CGP coverage is required for all construction activity that results in land disturbance of equal to or greater than 1 acre. Often, CGPs will have more significant requirements for active construction operations that equal or exceed 5 acres.

The EPA's most recent CGP was promulgated in 2017 and was challenged by the National Association of Home Builders because they allege that the EPA's CGP improperly expanded CWA liability to make any parties associated with large construction projects "severally and jointly" liable for any party's permit violation. That issue also would impact airports that hire general contractors for various construction projects and require those contractors to obtain CGP coverage and direct compliance. Under the EPA's 2017 CGP, not only would the airport and contractor be liable for any non-complying discharge but also any other tenant or party that contributes to the discharge could possibly be brought into any enforcement action. In response to the litigation, the EPA recently revised the 2017 CGP to fix concerns regarding a permittee's responsibilities and liabilities under the permit.

1.4.2.4 Guidance/BMP Manual Development by States

In response to the increased regulatory focus on stormwater in recent years, multiple states, through their transportation departments or state environmental agencies, have developed Stormwater Guidance Manuals or BMP Manuals, aimed at streamlining stormwater drainage design for airport projects. The manuals acknowledge that safety can be impacted by selection of stormwater BMPs and that certain BMPs with open water or specific vegetation can be wildlife attractants and are not appropriate at airports. The manuals typically have goals of meeting the applicable state and federal policy and regulatory requirements relative to stormwater design and treatment, while balancing the need for safety through careful BMP selection. Some of these manuals are comprehensive, including thorough discussions of regulatory applicability, an overview to educate the reader on airport operations, and discussions of hydrologic considerations. Examples of these manuals include stand-alone manuals developed by Washington State DOT (WSDOT) and Florida DOT, and a chapter within the North Carolina Department of Environmental Quality's (NCDEQ) Stormwater Design Manual. The manuals were typically developed as part of a cooperative interagency effort between the FAA, DOTs, and state environmental agencies.

The WSDOT *Aviation Stormwater Design Manual* in 2009 has a focus on stormwater BMP design modification for airports to reduce wildlife attractants.[156] The manual outlines a process which includes a design phase review of the specific species of concern for wildlife hazards at a particular airport, and the BMP selection and design considerations for infiltration-based and other BMPs factoring in the species of concern. The Washington State manual also includes adaptive methods/retrofit ideas for addressing existing open water BMPs on airports, such as fencing, netting, and floating covers.

The Florida DOT *Aviation's Statewide Airport Stormwater Best Management Practices Manual* was developed acknowledging that airports and airport operations are different than other types of regulated development.[157] The Florida DOT's manual relates only to airside drainage structural BMP selection, focusing on infiltration, with discussions of procedural BMPs, such as sumped fuel disposal, sweeping, turf management, and system maintenance.

The "Airports" chapter in the NCDEQ Stormwater Design Manual summarizes North Carolina's unique regulatory considerations relative to stormwater at airports, including that NCDEQ cannot require airports or development within 5 miles of an airport to use BMPs that promote standing water. The chapter also indicates that certain airports will be deemed permitted if they have certain conditions for overland flow for runoff leaving runways and taxiways, potentially exempting an airport project from the post construction requirements of the state stormwater program. Per the NCDEQ's manual, areas could be deemed permitted where pavements of a maximum width of 100 feet drain to a minimum width of 10 feet of vegetated receiving area, and the maximum pavement slope and vegetative area meet specifications per minimum design criteria outlined in the Stormwater Design Manual. The "Airports" chapter acknowledges safety concerns for certain BMPs and provides recommendations for appropriate BMPs and non-structural practices, such as property maintenance, pollution prevention, and soil amendments for promoting infiltration.

As stormwater regulations continue to evolve and more study is completed relative to airport stormwater quality and treatment options, these manuals could prove useful in other states to help with the permitting process and to potentially save airports money if less treatment is warranted for airside areas. Whether these manuals are merely "guidance" or serve as de facto minimum requirements in permits is an issue that is currently being debated and individual interpretation may depend on the particular state.

1.4.2.5 Climate Change/Design Storm Guidance and Implications

Until recently, the U.S. Weather Bureau's Technical Paper No. 40 *Rainfall Frequency Atlas of the United States* (known as TP-40), published in 1961, was a main source of rainfall data nationwide for a series of recurrence intervals (frequencies) and duration of storms. The report included a series of 49 rainfall frequency maps for the nation[158] and was used for decades by engineers in the design of stormwater systems, including those at airports. In recent years, National Oceanic and Atmospheric Administration's (NOAA) Hydrometeorological Design Studies Center has updated precipitation frequency estimates for most of the country in multiple volumes of NOAA Atlas 14. Atlas 14 incorporates newer and longer records of precipitation data and more weather stations than the prior TP-40. NOAA has established a Precipitation Frequency Data Server, a publicly-accessible application that allows users to access precipitation data associated with Atlas 14 by selecting the location-of-interest via a map interface. The new Atlas 14 allows users to predict storm frequencies for a site, using newer data that account for observed effects of climate change to date. However, NOAA Atlas 14 does not include estimates or predictions of forward-looking climate change effects.

As Atlas 14 becomes final for various regions of the United States, states and municipalities are expected to adopt the data as required design storm information for stormwater facilities associated with new development or redevelopment projects. In most cases, the design storm precipitation values are greater than those under TP-40, which could contribute to a need to treat and store increased runoff volumes, increasing costs for stormwater systems. Since capital airport projects that involve stormwater system designs often take years to go through the design, permitting, and funding process, projects that have not yet been constructed may have been designed using TP-40 data. Since the lifespan of drainage structures often exceeds 20 years, this leads to the question of how to integrate the new Atlas 14 data into current and future designs to better account for increasing severities of storm events.

1.4.2.6 Increased Focus on Green Infrastructure

Despite increased focus on green infrastructure, implementation at airports has been limited due to the associated challenges. However, there are strategies to incorporate green infrastructure at airports.

1.4.2.6.1 Drivers

Several drivers contribute to the increased focus on green infrastructure.

Regulatory Considerations: *ACRP Research Report 174: Green Stormwater Infrastructure – Volume 1: Primer*, found that stormwater regulations were a primary driver for airports considering green stormwater infrastructure (GSI).[159] At the federal level, the EPA encourages the incorporation of green infrastructure into stormwater management as a means to comply with NPDES and state permitting requirements.[160,161,162,163,164] Some municipalities have ordinances requiring use of low-impact development (LID) on new construction (e.g., Los Angeles).[165] States (e.g., Kentucky, Florida, and North Carolina) have written general stormwater permits for GA airports that encourage the use of GSI BMPs such as bioswales and vegetated filter strips.

Economic Benefits: GSI can be an economically viable means to improve surface water quality, address community concerns, and reduce the compliance risk of stormwater discharges. GSI practices may also involve lower capital and operations and maintenance (O&M) costs.[166,167] Airports subject to stormwater fees may be able to obtain credits for stormwater BMPs. Depending on the airport stormwater management program and the utility's credit program, fee reduction can be substantial. This can be particularly valuable as stormwater fee programs grow in popularity. There may also be water or energy savings if stormwater harvesting or green roofs are used.

Environmental Stewardship: Some airports are subject to municipal ordinances to use GSI or LID. Others undertake stormwater management initiatives that are "beyond compliance," or voluntary. For example, the Chicago Department of Aviation has made a visible commitment to the environment with the vegetated green roofs installed on top of 12 facilities at O'Hare International Airport.[168] Also, airports have adopted policies on sustainability practices in response to environmental concerns from state and local stakeholders. See the discussion below on sustainability considerations.

1.4.2.6.2 Challenges for Implementation

Although GSI has been implemented at several airports, ranging from GA to large hubs, the use of GSI at airports has generally been limited. The most common and critical concern is the potential for conflict with the FAA advisory to control wildlife hazards due to standing water or attractive vegetation.[169] Airports must meet the FAA requirements while simultaneously complying with local and state stormwater management regulations and land use regulations. Also, airport regulatory compliance experts, engineers, and regulators may be less familiar with the costs, construction needs, O&M, and performance of GSI and inclined to use conventional stormwater BMPs with which they have more experience, especially if the project is on an emergency basis. Finally, airports with prior soil or groundwater contamination are not appropriate candidates for stormwater infiltration or other GSI options. More data is needed on airport-specific designs and the effectiveness, O&M costs, and labor requirements.

1.4.2.6.3 GSI Strategies at Airports

GSI has been incorporated into stormwater management at airports as both retrofits and as part of larger capital projects. BMP selection and siting, however, are airport-specific and depend on factors such as land uses, soil types, and hydrology. In some cases, airports may already be using stormwater management BMPs that may be considered GSI (e.g., swales and filter strips); it is important for the airport and regulators to recognize the water quantity and quality benefits of BMPs.

GSI BMPs appropriate for landside are often the same as those used at other commercial properties (e.g., business parks or malls) and include bioretention cells, bioswales, and permeable pavements installed in and around airport parking lots, along access roads, and near terminals. On the airside, vegetated filter strips are the most commonly used BMP within the runway safety area. Austin-Bergstrom International Airport, for example, has sedimentation/filtration systems (Austin sand filters) throughout much of the airport for primary runoff management.[165] Wildlife hazards can be managed through timely BMP drainage, grass height maintenance, plant species selection, and predators. Where BMPs do have open water, airports have used strategies such as bird balls, nets, and dense vegetation. Some airports have adopted innovative approaches such as engineered filter media for metals removal or steep-sided ponds to discourage wading birds; such efforts have been done in collaboration with wildlife experts or university researchers and help further develop GSI options appropriate for airports.

1.4.2.6.4 Incorporation into Sustainability Programs

GSI can be incorporated into (and implemented in support of) airport and municipal sustainability planning and goals, which are often viewed as an extension of an airport's environmental commitments. The FAA's Airport Sustainable Master Plan (SMP) Pilot Program acknowledges the benefits of airport sustainability planning, including improved water quality. Examples of stormwater-related initiatives that have been included in airport SMPs include water reuse, evaluation of airport stormwater management, installation of GSI BMPs to prevent pollutants from entering receiving waters, and biodiversity protection for indigenous plants and wildlife.[170] Climate resilience is an emerging focus for airport sustainability practitioners. Both severe storms and sea level rise pose direct threats to airport operations and have received considerable attention in recent years. Adaptation of stormwater infrastructure is arguably the most critical element of an airport's ability to cope with these impacts.

1.4.2.6.5 Master Planning/Integration of Stormwater Management into Long-Term Capital Projects

In most cases, stormwater systems at airports have been developed over time, in conjunction with individual capital projects and based on observed deficiencies. This piecemeal approach has often led to a series of systems of varying age, some of which have been interconnected over time to alleviate capacity issues and adjusted in response to changes in airport layouts. This segmented approach can be an issue in understanding how the entire airport-wide system functions as a whole from a capacity, water quality, and spill response standpoint. Older systems at an airport also may lack treatment BMPs and may have been designed using precipitation frequency values that may now be outdated.

Evaluating the airport's stormwater systems more holistically to look for vulnerabilities and areas in need of improvement airport-wide can present opportunities for BMP retrofits, system separations or simplification, and capacity improvements that may extend beyond the direct footprint of an individual capital project such as an apron reconstruction but could have a positive effect on overall system functionality and water quality protection. Advance planning can also overcome obstacles such as potential land use conflicts and accommodate multiple uses in active areas, such as near the apron and ramp. Early planning during airport design can accommodate FAA guidelines and enhance airport operation. For example, GSI may be a useful tool for landside parking areas that must be buffered from the terminal building.

1.4.2.7 Waters of the U.S.

The term "waters of the U.S." (WOTUS) has caused much confusion and controversy and has resulted in a number of Supreme Court rulings. However, those rulings have failed to provide necessary clarity. On June 29, 2015, the EPA and the U.S. Army Corps of Engineers (USACE) (the agencies) issued a final regulation attempting to clarify what is and what is not a WOTUS (2015 Clean Water Rule). That rulemaking was challenged by states, regulated parties and non-governmental organizations in various federal district and appellate courts across the country alleging that the EPA and USACE had unlawfully expanded their CWA jurisdiction through the rulemaking. Initially, all of those cases were consolidated into the Sixth Circuit Court of Appeals, which ordered a national "stay" of the effective date of the new WOTUS definition. However, the Supreme Court subsequently found that the Sixth Circuit did not have jurisdiction and that challenges must originate in federal district courts, and many such challenges have been filed across the country.

While that litigation technically continues, the Administration took several actions, first to delay implementation of the 2015 Clean Water Rule and then to rescind it completely. The 2015 Clean Water Rule now has been fully replaced with a newly promulgated final WOTUS rule, which was published in the Federal Register on April 21, 2020 and became effective on June 22, 2020.

Additional information about the WOTUS definition and rulemaking (as well as related litigation) can be found at: https://www.epa.gov/wotus-rule/about-waters-united-states.

1.4.2.8 Evolving Site-Specific Water Quality Considerations

The aviation community is facing several water quality issues and challenges that are relatively site-specific. Some of these reflect evolution of issues that have been around for many years, while others are relatively new to airports.

1.4.2.8.1 Need to Understand Real Stormwater Characteristics

A few studies have been completed to date to review airside runoff stormwater quality at airports and potentially compare it to that of other land uses. Florida DOT and North Carolina State University (NCSU) have both conducted studies related to airport stormwater quality. The Florida DOT study,[171] which included data from 13 airports, concluded that nutrients and petroleum hydrocarbons were very low in airside stormwater and that there were limited metals identified at levels which could be pollutants (copper, lead, cadmium, zinc). The study indicated overland flow was an effective method for pollutant reduction for metals and could be a viable technique for treatment. North Carolina's Stormwater Design Manual indicates runway runoff is typically low in TSS, nutrients, and other pollutants; and that overland stormwater flow over grassed areas can provide significant volume and pollutant loading reductions. The NCSU study[172] stated the large existing expanses of grassy filter strips and swales at airports follow the disconnected impervious principles of LID. The study looked at the performance of existing grass swales at Wilmington International Airport compared to the performance of methods in a local residential development and indicated that the mean nutrient concentrations were comparable between the two land uses.

While some states have started to consider the characteristics of airside airport stormwater and need for BMPs, more study is needed to better characterize airport stormwater characteristics in multiple regions across the United States and to look at pollutant removals associated with existing swales. In some cases, airports are forced into the design of engineered water quality swales and other BMPs when existing filter strips and swales at these airports may already be providing adequate pollutant removals.

1.4.2.8.2 AFFF/PFAS Concerns

AFFF is used by airport fire departments to fight petroleum-based fires. Since the 1960s, AFFF formulations used at airports across the United States and Canada have contained fluorinated surfactants belonging to the chemical family of perfluoroalkyl and polyfluoroalkyl substances. PFAS surfactants provide excellent performance against Class B fires. This is reflected in the fact that only AFFF products containing PFAS meet MIL-F-24385 specifications, which FAA requires for AFFF products used at Part 139 airports.

Background on PFAS——PFAS represent a family of approximately 4,000 different man-made compounds that have been used in a variety of materials and industrial processes since the 1940s. PFAS have water-repellant, stain-resistant, nonstick, and surfactant properties. In addition to AFFF, PFAS have been used in the following:

- Paper tableware products such as paper cups, paper plates, and coffee cups
- Food packaging such as microwavable popcorn bags and fast food wrappers

- Commercial household products such as stain- and water-repellent fabrics, nonstick products (e.g., Teflon), polishes, waxes, paints, and cleaning products
- Industrial processes such as chrome plating, electronics manufacturing, and oil recovery

The EPA classifies PFAS as an emerging contaminant that is stable and breaks down slowly in the environment. Being highly soluble, PFAS are easily transferred through soil to groundwater. Because they do not readily break down, PFAS can accumulate over time in the environment and the food chain, including in humans. There is evidence that exposure to certain PFAS chemicals can lead to adverse health effects such as:

- Reproductive and developmental, liver and kidney, and immunological effects
- Tumors
- Increased cholesterol levels
- Abnormal infant birth weights
- Cancer
- Thyroid hormone disruption

Perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS) are two specific PFAS compounds that have been implicated with these impacts. Most western nations, including the United States, have banned the manufacture of these substances and phased out their use, although other PFAS compounds that are considered for now to have less environmental risk have been used as replacements. Additionally, these countries have begun developing advisory and regulatory concentration limits for PFOA and PFOS in drinking water, groundwater and other environmental media. In the United States, some states have taken the lead in developing advisory levels that are being used as the basis for actions regarding drinking water, fish consumption, and site contamination.[173]

1.4.2.8.3 Impacts on Airports

Airports face difficult challenges regarding these developments.

Current Operations——New generation AFFF products without PFOS and PFOA have entered the market. These new products contain shorter chain PFAS compounds, which to date have not been shown to present significant health or ecological risks. Although the new formulations are thought to present less risk, research into their health and environmental characteristics is ongoing, so it cannot be said with confidence that they do not present any future concerns.

Fluorine-free AFFF products have appeared in markets outside of the United States, but none of these products meet the current MIL-F-24385 specifications, which include a requirement that formulations contain PFAS. The commercial airport industry has instigated initiatives to change applicable FAA requirements such that that fluorine-free AFFF products would be acceptable, but it appears that such regulatory changes will require several years before they could be achieved. Congress has directed FAA to identify PFAS-free alternatives for Part 139 airports by October 5, 2021.

At the present time, AFFF products should be managed through operational and structural best practices to minimize exposure and release to the environment. Where AFFF is used for training and Part 139 certification purposes, containment and proper disposal of spent foam should be provided. Where AFFF is used in an emergency, it is recognized that responders will use whatever amounts necessary and in whatever locations required by the nature of the incident. Aircraft hangar fire suppression systems also may present environmental risk through accidental or necessary deployment because many of those systems also use PFAS containing foams.

Finally, unused stocks of the old AFFF formulations present a risk that may require special handling and disposal. The currently available alternatives for disposal of AFFF products and runoff containing those products are either high-temperature incineration or placement in a landfill permitted for hazardous wastes.

Legacy Impacts——One of the characteristics of PFAS is that the chemicals do not break down readily. This means past firefighting, training, equipment maintenance, and storage practices may have left legacy contamination. Soils may be heavily contaminated at old fire training sites, and that contamination may migrate to groundwater and beyond. Contamination may affect the cost and complexity of future airport development projects in these areas. Decontamination of fire trucks and hangar deluge systems requires aggressive measures to get concentrations in rinse water below advisory levels.

Several airports have found themselves in the situation where PFAS contamination has been detected in drinking water sources adjacent to or nearby their facilities. In these situations, response typically requires a site-specific effort involving technical, legal, and community affairs experts.

Available Guidance——These challenges can be overwhelming to airport staff who may be unfamiliar with the topics. There is a wealth of technical and regulatory information on the general topic of PFAS available on the internet, but much of it is not directly applicable to the airport context. *ACRP Research Report 173: Use and Potential Impacts of AFFF Containing PFASs at Airports*, was published in 2017 to educate airport staff and their consultants about AFFF issues, and provide them with practical guidance. The spreadsheet-based screening tool included in the report is particularly valuable in this regard. It helps airports identify areas of potential environmental concern associated with historical or current PFAS use and plan appropriate BMPs. The report and spreadsheet tool can be downloaded at no cost from ACRP's website.[174]

1.4.2.8.4 Road Salt

While airport winter maintenance pollution prevention tends to focus on aircraft/airfield deicing, chloride contamination in fields, lakes and streams, and drinking water sources from non-airside deicing is a growing concern in colder climates as well. Airports often have large parking areas/structures and roadways where chloride salts (e.g., rock salt, calcium chloride) are used for deicing. Chloride salts are non-biodegradable and accumulative and some regulatory agencies, especially in the upper Midwest, are beginning to issue chloride reduction/monitoring programs and standards. Airports should be aware of these growing concerns.

1.4.2.8.5 Wet Weather Standards/Variances

The EPA has developed water quality standards (WQS) for many pollutants regulated through the NPDES permit program. Virtually all WQS are based on studies that assess the environmental risk to aquatic species or human health that assume a constant wastewater discharge that exists 24 hours a day, 7 days per week. In addition, those standards are established for highly conservative, very low flow conditions to ensure more than adequate protection during virtually any discharge scenario. Typically, those standards are expressed for short duration (acute) and for longer duration (chronic) scenarios. However, the EPA has never developed wet weather WQS that accurately reflect that wet weather conditions are highly episodic and by their very nature are not associated with "low flow" scenarios. Hence, applying existing WQS based on sustained dry weather conditions to stormwater flows is overly conservative, but because of the lack of wet weather WQS, permitting authorities have little else to substitute. EPA issued a memorandum on *Interim Strategy for Per- and Polyfluoroalkyl Substances in Federally Issued National Pollutant Discharge Standard Permits*[175] in November 2020.

Fortunately, most stormwater permits rely upon non-numeric BMPs in lieu of numeric effluent limits that likely would reflect existing WQS. Airports should be aware of these issues in negotiating NPDES permits. When WQS are applied, airports may be able to pursue relief from those numeric standards either through obtaining either a variance or an extended compliance deadline.

1.4.3 RESEARCH NEEDS

To help achieve the vision, airport sponsors, agencies, vendors, and other stakeholders need research to address the following topics.

- Guidance on how the benefits of technologies and practices for reducing amounts of deicers required for safe operations can be incorporated into NPDES permits and other compliance obligations
- Development of new analytical tools and industry applications based on the BOD Management Capacity Index developed by the Voluntary Pollution Reduction Program
- Updates on the impact of airport pavement deicing products on aircraft and airfield infrastructure
- Exploring ways to inform airport operators on the most current technical, regulatory, and legal developments regarding PFAS at airports
- "Fingerprinting" existing AFFF formulations so that airports have better reassurance that PFAS contamination near airports can readily be traced to AFFF use and not some other off-site source of PFAS
- Disposal of older stocks of AFFF products that may still be stored at airports, as well as soil and/or groundwater management practices where PFAS contamination is found or expected
- Solutions to assist the industry in responding to evolving site-specific water quality considerations
- Review of existing and/or development of new methods and models for incorporating estimates of potential effects of climate change into design development for airport stormwater systems
- Nationwide analysis of primary and smaller GA airports that reviews the characteristics of airside stormwater runoff, including stormwater quality from pavements and after passing through vegetated swales before entering stormwater systems to determine whether

existing swales provide adequate treatment, as has been suggested by some states and prior limited case studies

There is also 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 role technologies and practices for reducing amounts of deicers required for safe operations play in significantly reducing the environmental impacts of those operations.
- The possible impacts of using newer hybrid airfield pavement deicers that may create tension between longer carbon brake life and water quality concerns because of higher BOD and COD content. More work may be needed to balance these issues on an airport-specific basis.
- New applications for the analytical tools developed by the Voluntary Pollution Reduction Program.

1.4.3.2 Stormwater Management

- Continuing research on stormwater treatment BMPs at airports in response to new regulations, new design storm guidance, new technologies, and a changing focus toward green infrastructure solutions and the use of methods that are not wildlife attractants.
- Incorporation of NOAA Atlas 14 into design criteria to replace prior, less complete data sources for design storm development with potential integration of estimates of forward-looking climate change for design storm development. Research may also be needed to track developments in the utility and challenges in national or regional climate change estimates (e.g., downscaled models created from global climate models) and how they can best be used for updating design storms.
- Ongoing research on stormwater quality at airports that may alter current regulatory requirements.
- Continuing research on the costs and performance of structural BMPs in airport settings.
- Improved ability to demonstrate and convey the effectiveness of existing stormwater BMPs in managing water quality and quantity in order to help permitting authorities better understand the full extent of treatment provided by the airport's existing stormwater management program (e.g., swales or filter strips providing water quality treatment).
- Ongoing exploration of ways to customize the designs of structural BMPs to meet airport development, space, regulatory, and other needs, as well as the applicability of innovative approaches to airports.
- Additional work on developing wet weather related water quality standards or more appropriate ways of modifying existing water quality standards for wet weather events is critical for ensuring that airports with numeric effluent limitations are not wasting resources attempting to comply with overly conservative standards. The 2019 NAS study[176] provides initial insight into some of these critical issues.

- There is a widespread need to research how airport stormwater management is being integrated with local/regional stormwater and water quality management. Local entities, including those tasked with stormwater management or overall watershed management are under stress and may be looking to reduce or eliminate airport contributions to MS4 systems or receiving waters.

1.4.3.3 AFFF/PFAS

- Communication strategy for informing airport operators on the technical, regulatory and legal developments regarding AFFF formulations, operational practices involving current fluorinated-AFFF and other products, and addressing legacy PFAS contamination.

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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

In November 2018, NOAA issued the *Fourth National Climate Assessment*, describing the dire impacts of climate change across the United States and specifying regional effects facing the nation. Both federal and non-federal stakeholders contributed to the report's development, which was overseen by a federal steering committee made up of 13 federal agencies. In comparison to prior reports (required at least every four years per the Global Change Research Act of 1990), the most recent report places a greater emphasis on the immediate need for adaptation and resilience, not solely mitigation or slowing of climate change via GHG emission reductions. The report states that our communities and infrastructure will face major challenges over the next decade, even if drastic changes reduce the rate of emissions and slow the global temperature increase. Action must occur now to limit the economic, social, and environmental consequences that the country is already facing due to climate change. The report discusses the importance of adaptation and striving toward resilience, which it defines as follows:

1. Adaptation – Adjustment in natural or human systems to a new or changing environment that exploits beneficial opportunities or moderates negative effects.
2. Resilience – A capability to anticipate, prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to social well-being, the economy, and the environment.[177]

The aviation industry has already experienced the impacts of climate change. Recent weather events (e.g., record-breaking heat waves, drought, flooding and extreme storms) have increased awareness of the importance of planning for future climate conditions and associated risks to airports' infrastructure and operations. This chapter presents background information on projected climate changes and weather, current government adaptation initiatives, gaps in current planning and research, considerations regarding potential operational impacts, and describes a future vision for airports. This chapter also summarizes recent research and ongoing research needs, which are a focus of the TRB.

Proactive assessment and the resulting implementation of measures to minimize risk of changing weather and its damage to infrastructure, interruption of operations, and economic losses is necessary. For airports, this means incorporating region-specific climate projections into existing and new airport planning processes, which 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.

The focus of this chapter is to first provide an update on the general state of adaptation planning in both the United States, as well as countries across the world. Secondly, it documents the efforts completed since the previous E-Circular to identify remaining research gaps with the ultimate goal of integrating adaptation and resilience inherently in all actions and planning going forward.

The Council on Environmental Quality (CEQ) issued a final rule in July 2020 updating their regulations implementing the procedural provisions of NEPA (see Section 3.1.3). Although not specific to research gaps and needs (the focus of TRB), the final rule could influence future activities and may indicate a decreased focus on federal investment/consideration in climate change. The CEQ final rule includes a number of measures to streamline the environmental review process including the removal of cumulative impacts in NEPA evaluations, as well as limiting analyses to "reasonably foreseeable…and close causal" effects.[178] This scales back the climate change analysis within a NEPA document, as climate change is a global issue associated with GHGs.

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 11 terms that are commonly used in climate change adaptation discussion and research.

Adaptation: Adjustment in natural or human systems to a new or changing environment that exploits beneficial opportunities or moderates negative effects.[179]

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

Climate Change Adaptation Planning and Preparedness: Activities taken 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 should involve 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.

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 (GCM) 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 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.[180] For example, the IPCC released a *Special Report on Global Warming of 1.5 °C* in 2018, which summarized the likelihood of climate changes of 1.5 °C compared to 2 °C, showing substantial differences between the two on projections such as sea level rise, precipitation/drought, and ice sheet stability, among others.[181] Climate change projections such as these 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 CO_2, methane (CH_4), NO_x, sulfur hexafluoride, hydrofluorocarbons, and perfluorocarbons emitted from human activities and natural systems into the atmosphere that 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. The GHGs that have been released over the last 50 to 100 years would continue to cause unavoidable climate change even if emissions ceased immediately.

Resilience: A capability to anticipate, prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to social well-being, the economy, and the environment.[182]

Risk: The potential for loss from climate change stressors, including loss of operations and infrastructure.

Risk Assessment: Risk assessments are evaluations of an organization's 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."

- 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. Risk assessments consider 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 considered during a risk assessment. Uncertainty may also occur in assessment of magnitude or likelihood. For example, the 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 temperature extremes; and increased risk of heat waves, areas affected by drought since the 1970s, and frequency of heavy precipitation events.[183]

Vulnerability: Weaknesses or gaps in infrastructure, operations, or communication, that increases risk. Vulnerability assessments evaluate the combination of exposure and resilience of a particular asset or operation.

2.1.1.2 Prior Efforts: Pre-2014

The following sections summarize research related to climate change adaptation and preparedness completed prior to 2014 and thus documented in the previous E-Circular.

2.1.1.2.1 Worldwide

Various organizations are working to advance the understanding of climate change impacts and strategies to adapt to the changes. In 2018, the Airports Council International (ACI) published a policy brief titled *The Airports' Resilience and Adaptation to a Changing Climate*. This brief highlights the impacts of adverse weather events may have on operations and safety, as well as business at airports globally, and recommends conducting risk assessments to define their adaptation plans for both existing and new infrastructure and operations. The brief includes case studies from airports in Norway, Australia, Hong Kong, Istanbul, Amsterdam and Singapore. Potential climate stressors and their related potential impacts on infrastructure and operations are identified, along with recommendations.[184]

Additionally, ICAO also recognizes the impact of climate change on aviation. In 2010, ICAO 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.[185]

International support for research on climate change adaptation is helpful to address climate change challenges at a global level. However, impacts vary across geographical regions.

2.1.1.2.2 Europe and United Kingdom Airport Efforts

In 2013, EUROCONTROL, the European Organization for the Safety of Air Navigation, published a report titled *Challenges of Growth Task 8: Climate Change Risk and Resilience*. 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.[186]

In addition to EUROCONTOL's broad efforts, there are other country-specific initiatives such as the United Kingdom's (U.K.) Climate Change Act of 2008, which provides information, offers direction and guidance on climate change, and serves as a foundation for work on climate change adaptation within the U.K. 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 and several of these airports continue to post updates on their plans.[187]

2.1.1.2.3 North America

As documented in the 2014 E-Circular, President Obama signed Executive Order 13514, *Federal Leadership in Environmental, Energy, and Economic Performance*, in 2009, which contained a provision for the incorporation of climate change adaptation into policies and practices at federal agencies. (This has since been revoked.) In accordance with the implementing instructions from CEQ for Executive Order 13514, the U.S. DOT issued a Policy Statement on Climate Change Adaptation in June 2011. This policy statement committed 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."[188] The FAA showed support of the U.S. DOT's efforts to meet the goals it set forth in the 2011 Policy Statement. In 2012, the U.S. DOT committed to three priority actions for implementation, tools, planning, and asset management. Following direction from the U.S. DOT, the FAA surveyed its own programs and needs and committed to three priority actions to address climate change, one for each of the three U.S. DOT action categories (tools, planning, and asset management). These U.S. DOT and FAA actions were included in the 2014 Department of Transportation Climate Adaptation Plan.[189]

Each of the following FAA priority actions has airport applicability and can benefit the entire aviation community.

FAA Tools Action—The FAA "tools" action culminated in the Common Support Services–Weather project (CSS-Wx), a data dissemination tool that distributes unified weather information instantaneously across the NAS. This information is used to increase efficiency in the air traffic system by better predicting where delays due to weather may occur.[190] As the climate changes, better weather data are vital to ensuring efficient operations within the NAS.

FAA Planning Action—The FAA "planning" action involves airport sustainability planning. The FAA provides grants to airports to develop airport SMPs or airport sustainability management plans (originally as a pilot program and now under regular AIP funding). Airport SMPs incorporate sustainability considerations into an airport master plan, while airport sustainability management plans are stand-alone documents that focus solely on sustainability. Both document types use a similar process: development of an airport sustainability policy, a baseline assessment of airport activities, and identification of initiatives that can make the airport more sustainable. Many of these pilot projects address climate change and/or GHG emissions.

As of January 2019, 44 airports received FAA funding for sustainability planning documents. The FAA's airport sustainability planning efforts enable individual airports to evaluate the potential effects of climate change that anticipate site-specific vulnerabilities, and develop initiatives that will improve the resilience of their infrastructure. A listing of airports with individual plans as well as some of the plans themselves can be found at the following website: https://www.faa.gov/airports/environmental/sustainability/.

FAA Asset Management Action—The FAA "asset management" action was 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 adaptation needs.

2.1.1.2.4 Airport Cooperative Research Program

The 2014 E-Circular documented TRB efforts that were specifically focused on adaptation and resilience. This focused primarily on *ACRP Synthesis 33*: *Airport Climate Adaptation and Resilience*, which evaluated climate change adaptation initiatives, challenges, and motivation for action based on the results from a survey of 20 airports to understand current practices for considering climate change adaptation in airport planning. The synthesis included case examples illustrating different airport climate adaptation actions in Alaska; Jacksonville, FL; San Diego, CA; Atlanta, GA; Oakland, CA; Toronto, Ontario, Canada; Dallas and Fort Worth, TX; and Jackson, MS.[191] At the time, most airports that were planning and adapting to climate change were located in areas that had faced heavy storm events and/or were highly susceptible to sea level rise. There were limited tools and resources available to understand specific risks and vulnerabilities airports would face, which has since gained attention in the research field.

2.1.2 CURRENT STATE

It is important to understand what has occurred since the last update of this document in 2014 when determining next steps in climate adaptation planning. The general trends associated with climate change adaptation are described below relative to the world and the United States. Strategic changes have been spurred by an increase in the number of extreme events and the costs of those extreme events, illustrating the need for additional efforts and research to mitigate future compounding of these impacts over time.

2.1.2.1 Worldwide

From 2014 to 2019, the focus was primarily on building tools to assist with adaptation, creating compilations of BMPs, and providing additional research to support adaptation efforts. This section includes a spotlight on several milestones in the past few years relative to climate adaptation worldwide, as well as several examples relative to transportation, and aviation, to understand both global- and industry-level efforts.

2.1.2.1.1 International Commitments and Goals

The Paris Agreement within the UNFCCC was a landmark agreement to combat climate change and adapt to the effects of climate change, focusing on GHG emission reductions, adaptation, and financing, implemented in a phased approach. The Paris Agreement was ratified in November 2016 when 55 countries signed. Since then, 189 parties have ratified the agreement. This agreement includes several key areas including a long-term temperature goal, mitigation, and resources aimed at achieving a balance between mitigation and adaptation.[192] Mitigation is further detailed in Section 2.2, Carbon Reduction and Management. This agreement provides international indication of the increased focus on both mitigation and adaptation planning. The UNFCCC continued discussions over the Paris Agreement at subsequent Conventions including at the 25th Conference of the Parties in Madrid, Spain.

In 2016, the United Nations Development Programme released the Sustainable Development Goals, which support climate change resilience and risk management through sustainable development.[193] These goals focus on developing countries but illustrate the increasing focus on adaptation planning.

2.1.2.1.2 Information Exchange

The IPCC *Global Warming of 1.5 °C* report provides further information on the impact of global warming. This report is "an IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global GHG emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty."[194] The report offered projections on elements such as sea level rise for 1.5 °C increase in global temperature compared to 2 °C, information that can be used for adaptation planning.

The EU has a platform to help Europe adapt to climate change. The European Climate Adaptation Platform (Climate-ADAPT) is a partnership between the European Commission and the European Environment Agency. The site helps users to access and share data and information on climate change, vulnerability of various regions, adaptation strategies, case studies, and tools.[195] The site promotes three key steps in furthering adaptation and resilience: (1) promoting action by member states (adaptation strategies and plans), (2) better informed decision-making (e.g., reducing the knowledge gap, creating a platform with all adaptation information), and (3) identifying key vulnerable sectors.

The United Nations Conference on Trade and Development released a Climate Risk and Vulnerability Assessment Framework for Caribbean Coastal Transport Infrastructure. It addresses lessons learned for climate adaptation planning and include how adaption is often linked to policy decisions about risk, communication, financial, communication hurdles, and the need for regional cooperation.[196]

In addition, there were several relevant ICAO updates. The 2016 Environmental Report, *On Board a Sustainable Future* (Chapter 7, Climate Change Adaptation and Resilience) presents the work of CAEP and identifies climate change impacts relative to aviation. It also identifies the need for further research on local effects of climate change on aircraft and airport operations.[197] ICAO has also included a chapter on climate adaptation and resilience in the ICAO Airport Planning Manual, Part 2, recommending that adaptation and resilience be incorporated into standard airport planning. Integrating resilience and adaptation considerations into planning at the start of a process is more cost efficient and effective in mitigating impacts over time.[198]

Although not specifically intended for aviation, previous estimates from the World Bank place the cost to adapt to climate change between $70 to $100 billion (B) annually for the period 2010-2050. The current (2011) Adaptation Finance Gap Report shows that the cost of adapting to climate change in developing countries could range between $140B and $300B per year in 2030, and between $280B and $500B per year in 2050.

2.1.2.1.3 Transportation Planning

Specific airports also conducted adaptation planning. For example, Heathrow Airport released their *Climate Change Adaptation and Resilience Progress Report* in 2016.[199] As the importance of adaptation planning becomes more apparent and as better projection and cost data is released, more airports may complete resilience planning efforts. Additionally, in early 2020, the United Kingdom Court of Appeal ruled that the government's plan to build a third runway at the country's largest airport is illegal on the grounds that it did not appropriately consider climate change commitments. This was a landmark decision, and judges expressly cited the 2015 Paris Agreement as grounds for the ruling.

2.1.2.2 United States

From 2014 to 2016, the Obama Administration continued its commitment to policy-making, supporting federal programs to address and plan for climate change. This included signing the Paris Agreement in December 2015, the first comprehensive action among United Nations members to combat climate change and adapt to its effects.

Leading up to and following the Paris Agreement, the Obama Administration initiated several programs aligned with its principles. The federal government and associated agencies developed resources to promote local planning and preparedness, including, but not limited to:

- The EPA's Adaptation Resource Center (ARC-X), an interactive resource to help local government decision makers create an integrated package of information tailored specifically to their needs and to effectively deliver services to their communities even as the climate changes.[200]
- The U.S. Climate Resilience Toolkit, which provides resources and frameworks to understand and address climate issues that affect communities nationwide.[201]
- The U.S. Climate Data Portal provides datasets from federal agencies and other public-sector organizations to help inform and prepare America's communities, businesses, and citizens.[202]
- NASA's Global Climate Change provides science agencies, planning organizations, and decision makers with the scientific data needed to understand climate change.[203]
- Federal Emergency Management Agency's Emergency Management in a Changing Climate provides emergency managers with tools and data to help them manage climate-related risks and advance preparedness efforts.[204]
- U.S. Department of Energy's Climate Change webpage supports research and innovation that makes fossil energy technologies cleaner and less harmful to the people and the environment.[205]

In 2016, the new Administration led to a shift in climate change action and planning at the federal level. In the summer of 2017, the president announced his intent to withdraw from the Paris Agreement and in 2019 began the formal process for withdrawal. Despite this action, many state, regional, and local governments remained committed to tackling climate change, as evidenced by over 400 city mayors joining Climate Mayors, a bipartisan coalition determined to work toward the Paris Agreement's goals.[206] Climate Mayors, along with other organizations like We Are Still In (corporations and civic groups),[207] America's Pledge,[208] and C40 (a global network of megacities focused on climate change)[209] continue to set targets and take steps toward mitigation and adaptation to minimize the impacts of climate change. In November 2018, the federally mandated Fourth National Climate Assessment helped underscore the importance of adaptation within the next decade.[210]

Since 2014, adaptation and resilience planning has gained the interest of the aviation industry as airports across the country experienced the effects of climate change or were faced with difficult questions about their preparedness should an event occur. Airport sponsors like the Massachusetts Port Authority (Massport), the Port Authority of New York and New Jersey (PANYNJ), and the San Diego County Regional Airport Authority (SDCRAA), which are highly susceptible to storm surge and flooding given their facilities' coastal locations, have integrated resilience and adaptation into their planning and design/construction efforts. For example, the PANYNJ has a resilience and adaptation chapter included in their Design Guidelines.[211]

A crucial initial step in the resilience and adaptation planning process involves determining an airport's risks and vulnerabilities. This may be straightforward in a coastal region or area that has already faced devastating storm events; however, airports with less tangible or frequent impacts have struggled with this assessment. The need for resources and tools to assist these efforts was reflected in the TRB's release of *ACRP Report 147: Climate Change Adaptation Planning: Risk Assessment for Airports*.[212] The report includes guidance to aid airports and consultants in understanding climate change impacts on operations, facilities and infrastructure, and other crucial activities. The guidebook includes potential adaptation measures and supports their integration into airport planning processes. There is also an accompanying, electronic assessment tool called Airport Climate Risk Operational Screening (ACROS). The tool uses a formula to compute an estimated level of risk for assets and operations at an airport. These airport-specific risks are then ranked to provide an enterprise-level estimate of the relative risk posed by each asset and operation.

ACRP Report 147: Climate Change Adaptation Planning: Risk Assessment for Airports, has been used by a number of airports; however, the report does have some limitations. For example, the ACROS tool is based on climatological data from other external resources. Without frequent updates, the data may be dated and thus affect the usefulness of the tool.

Another key climate change related project was *ACRP Report 160: Addressing Significant Weather Impacts on Airports*. A wide range of research findings show that individual impacts of significant weather are amplified due to climate change, and there is increasing evidence that frequency of events may be influenced as well.[213] The resource provides a toolkit for airports to better prepare and respond to severe weather events. The project includes a literature review and research task to identify airport resource gaps, a survey of airport operators to assess current operational practices, 15 detailed case studies for more in-depth study of major weather impacts and best practices at actual airports, and weather maps for events from 2004 through 2013 to identify individual airport vulnerabilities. The Airport Weather Advanced Readiness (AWARE) toolkit included in *ACRP Report 160* features a user-friendly, multi-component planning toolkit for specific airports to address weather preparation and response needs based on the findings from the weather data. For example, the toolkit could help airports identify how better to protect critical assets and prepare response teams prior to weather related disruptions. Airports can complete a self-assessment to identify their risks and obtain high-level recommendations. To obtain more robust guidance, users can input specific information across a wide range of airport lines of business. The tool also features a mechanism to track weather impacts over time for comparative and economic analysis.

In addition to *ACRP Reports 147 and 160*, *ACRP Research Report 199: Climate Resilience and Benefit Cost Analysis – A Handbook for Airports* acknowledges another challenge to airports – the ability to determine the costs and benefits of resilience and adaptation measures and prioritize these in the planning and budgeting process. Many measures to address climate change do not result in quantifiable revenue increases or cost savings that can be easily determined based on existing patterns and activity projections. Instead, these measures may help minimize risk, reduce disruptions to activities, or provide other benefits that are more challenging to quantify financially or occur over a longer period. The ACRP project recommends "Benefit Cost Analysis (BCA) as a potentially useful method to balancing gradually realized, unconventional, and risk dependent benefits with upfront financial costs of adaptation investments. If appropriately applied, BCA can help airport administrators better understand and demonstrate the tradeoffs of investing in climate adaptation measures in the context of recognized uncertainties."[214] The handbook will assist airports in determining BCAs while considering the unique challenges of the aviation environment. The report provides guidance and tools to support the evaluation of infrastructure investment strategies in the context of ensuring climate-related resilience.[215]

Lastly, ACRP project 10-26, "Airport Microgrid Toolkit," is underway. Recognizing the potential contribution to resilience, the toolkit will provide guidance for evaluating and implementing microgrids at airports.[216] As of the *FAA Reauthorization Act of 2018*, microgrids are now AIP eligible.[217] It is anticipated to be an area of growth due to the eligibility and the focus from ACRP on how to evaluate and implement microgrids at airports.

While previous focus from the FAA had been on developing and implementing a sustainability planning pilot program, in 2013, the FAA issued its last stand-alone sustainability planning grant. While sustainability planning grants became eligible under AIP, with the removal of a separate funding source, stand-alone sustainability plans and fully integrated SMPs have been declining among the smaller airports. In general, the trends have seen smaller airports focusing less on sustainability. Larger airports or airports with more local funding available have continued their sustainability planning efforts, including updates to the plans, implementation of recommendations, and climate action planning elements that were included in many of these plans. Additionally, airports have made efforts to participate in the Airport Carbon Accreditation Program (ACA) through ACI. While the program focuses on mitigation rather than adaptation, the program has increased the focus on climate change at airports across the country.

In addition to the progress made in researching and developing tools for resilience and adaptation, the aviation industry has sought to address its role in climate change. As discussed in separate chapters, airports, airlines, and manufacturers are taking action to reduce GHG emissions associated with air travel via sustainable aviation fuels, new technologies, and operational practices. Mitigation efforts are further explained in Section 2.2, Carbon Reduction and Management.

2.1.2.3 Observations on Shifts in Focus Since 2014

The focus of efforts to address climate change shifted from reducing GHG emissions to adaptation and resilience.

2.1.2.3.1 Worldwide

Since 2014, there has been an increased number of extreme events and tangible impacts of climate change are being reported on a more frequent basis. Worldwide, it seems that the validity of climate change is not in question and the direction has shifted to mitigation and adaptation. From the information above, several themes have surfaced, which helps guide and narrow the next steps needed to further adaptation planning on a worldwide stage. These themes include:

- Increased attention on costs of resilience efforts and support for developing countries to propose resilient growth
- Focus on the fact that resilience plans help identify needs, but resilience needs to be integrated at every level including planning, design, construction, and operation to be effective in the long term
- Focus on creating centralized locations for information on resilience and adaptation planning as more research is developed and additional issues/solutions arise

2.1.2.3.2 United States

Since 2014, on a nationwide level in the United States, changes in Presidential Administrations have altered government policy. However, due to existing lines of research, ACRP and other local programs have been successful in completing several projects to further climate adaptation and resilience planning. Several of these improvements and trends in the United States are summarized below.

- Improvements in the confidence of climate change projections particularly for extreme short-duration events.
- Greater understanding of site-specific risks and vulnerabilities of airports to climate change based on downscaled climate change prediction modeling. This includes an emphasis on determining the criticality of infrastructure and other assets at an airport to prioritize actions.
- Increasing attention on short-term hazards/acute events like power outages and expectations for back-up plans. Given the interconnectedness of the aviation network, this includes planning for events at other airports with potential to cause delays and disruptions at the subject airport.
- Increased focus on airports supporting emergency preparedness and response (leveraging airports' link to their surrounding communities and ability to serve as a resource in the wake of climate-induced events).
- Increasing need for resilience metrics/focus areas. The understanding of traditional resilience metrics is evolving, and sea level is one of many metrics that need to be tracked. Examples of others gaining exposure include the following:
  - Temperature, particularly heat-affecting elements like terminal energy loads and infrastructure planning and design (e.g., to avoid planes "sinking" into airfield pavement)
  - Humidity and the effect of humidity on dust storms
  - Precipitation (amounts and frequency) to help plan for extreme events

- Pavement/soil stability
- Deicing guidelines and needs
- Emergency and operations staffing needs
- Communication planning for resilience purposes

2.1.2.4 Climate Change Resiliency (2020 and Beyond)

Future research projects focus on aviation climate adaptation and resilience, understanding effects, design criteria, and risk management, in addition to other needs.

2.1.2.4.1 Where Are We Going (5-Year Vision)

Building on past research and accounting for the current political climate, this section strives to create a vision for the next 5 years for aviation climate adaptation and resilience. While other sections focus more on the technological drivers for this vision, this section focuses on the planning needs to support further resilience in the aviation system. The one clear underlying trend is the need to take adaptation and resilience planning to the next level and ensure that it is integrated into all actions and decisions. Planning efforts that take climate change resilience and adaptation into account are considered good planning going forward. Airports that fail to consider the projected climate-related issues could put their facilities and communities at risk, creating rising costs and issues. The ultimate 5-year vision is to integrate climate change adaptation and resilience planning into all facets of planning. The primary method of doing this will be through identifying and updating planning criteria. There are several elements that will support this vision, as discussed below.

2.1.2.4.2 Greater Understanding of Effects

The aviation industry would benefit from a greater understanding of: (1) the potential changes from climate change particularly for extreme short-duration events (part of this vision is addressed further in the water and stormwater issue in Section 1), and (2) the full extent of climate change-induced effects on an airport’s ability to operate efficiently in the future (e.g., scale of impacts associated with increased storm surge, higher temperatures, rising sea levels). It would also be useful to evaluate the NAS network effects of increased turbulence and higher-energy storms and increased flight delay events.

2.1.2.4.3 Information-Sharing

Expanded information-sharing among airports and communities on how they assess their vulnerabilities and prioritize adaptation actions would contribute to greater efficiencies and collaboration moving forward.

2.1.2.4.4 Design Criteria

The industry will need to understand how planning and design criteria for infrastructure need to be altered to address climate change. This would cover:

- The types of planning criteria needed for infrastructure based on modeled effects of climate change, such as:
  - Terminal sizing and needs (e.g., heating, ventilation, and air conditioning [HVAC] systems; size, energy, and distributed energy resources such as renewable generation, battery storage, and microgrid capabilities)
  - Airfield and landside planning criteria (e.g., runway length requirements, storm water design, and understanding the need for redundant systems and impact of climate change on operations)
- Methods to update planning for operations, staffing, equipment purchases, communications plans/outreach to staff, roadway planning, integration with the local and regional entities to account for resilience screening methods.

2.1.2.4.5 Costs and Risks

Trends show the focus on adaptation planning is generally linked to risk management, so additional research is required to document impacts to provide the link between risk and costs, particularly relative to aviation. Part of assessing costs could include co-benefits associated with climate resilience such as resistance to cyber-security threats and revenue generation that is possible with enhanced energy load management and on site generation.

2.1.2.4.6 Aviation System Information

In addition to specific risks for airports, the aviation system also needs similar research on the potential worldwide impacts of climate change on the aviation system, including system wide delays and economic impacts, among others.

2.1.3 FUTURE VISION

Continued efforts toward improving aircraft technology including hybrid and non-traditional air frames, increasing efficiency through operational changes, developing internationally accepted policy measures, as well as adopting alternative aviation fuels on a large scale will be critical toward mitigating aviation climate change due to CO_2 emissions. Periodic accounting and course corrections toward achieving established goals are also critical to guarantee sustainable growth of commercial aviation.

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.

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.

Future research projects are focused on reducing emissions of aircraft CO_2, NO_x, PM, SO_2 and lead in aviation gasoline. These future efforts will provide (1) a better understanding of particulate matter; (2) a better appreciation of aviation impacts on communities, including what sources are causing the impact; and (3) mitigation measures to reduce the impact these sources are having on local air quality.

2.1.3.1 Aviation Sustainability Center

As reviewed in Section 1.1.2.6, ASCENT works to create science-based solutions for the aviation industry's biggest challenges.[218] The projects undertaken by ASCENT researchers fall into the general categories of alternative jet fuels, emissions, noise, operations, and tools. The categories with potential fuel and emission reductions include:

- Sustainable Aviation Fuels: ASCENT is working to facilitate the development and introduction of sustainable aviation fuels. Researchers are developing innovative and cost-effective production and distribution systems, evaluating how sustainable aviation fuels will affect emissions, air quality, and engine performance, and creating more concrete standards for sustainable aviation fuel certification.[219]
- Emissions: To help the industry comprehend and address concerns about emissions, ASCENT researchers are analyzing data and improving models to better understand the effect of aircraft emissions, creating and refining analysis techniques on airport-specific and global scales, and assessing how policy changes could affect emissions.[220]
- Operations: ASCENT research is focusing on airport surface movement, cruise altitude and speed optimization. The nature and scale of these effects depends on a multitude of related factors such as an aircraft flight path on approach to and departure from the airport, the flight speed and cruise altitude, and the path the aircraft follows while on the ground. Aviation operations can be optimized to reduce the amount of noise and emissions generated by these operations while still maintaining the efficiency of the airport system.[221]
- Tools: The FAA suite of tools has been developed to provide the ability to characterize and quantify the interdependences of aviation-related noise and emissions, impacts on health and welfare, and industry and consumer costs under different policy, technology, operational and market scenarios. ASCENT researchers are further developing and expanding the capabilities of these tools in a variety of ways ranging from improving the way basic physical properties are represented and modeled to how new technology will enter the fleet and what will be its benefits.[222]

2.1.3.2 CAAFI® and Piston Aviation Fuels Initiative

The FAA and its partners under CAAFI® will continue their efforts to support the development, approval, and deployment of alternative aviation fuels that have positive impacts on aircraft emissions and air quality through reductions in PM, SO_2, and life cycle CO_2 emissions. Activities under NextGen include the exploration and qualification of additional classes of sustainable aviation fuel blends that use novel feedstocks and conversion processes. Approval of fuel blends exceeding 50 percent sustainable aviation fuels will extend these air quality benefits by further reducing PM, SO_2, and life cycle CO_2 emissions.

To help "get the lead out" of AvGas, the FAA is supporting the research of alternate fuels at its William J. Hughes Technical Center in Atlantic City, NJ. They are working with the aircraft and engine manufacturers, fuel producers, the EPA, and industry associations to overcome technical and logistical challenges to developing and deploying a new unleaded fuel. Phase 1 and Phase 2 testing of selected fuels under the Piston Aviation Fuels Initiative revealed unique issues that needed to be addressed. Completion of the fuel testing was delayed in 2020; the tentative schedule plans to re-start in 2021.[223]

Case Study; ASCENT Project 022: Evaluation of FAA Climate Tools - Use of Coupled Chemistry Climate Models to Estimate 2050 Climate Effects of Aviation

The FAA's Center of Excellence for Alternative Jet Fuels and the Environment is a cooperative research organization led by the Massachusetts Institute of Technology and the Washington State University. ASCENT Project 022 "Evaluation of FAA Climate Tools: Aviation Environmental Portfolio Tool (APMT)" focuses on the evaluation of modeling tools and datasets, specifically FAA's APMT. One of the studies analyzed the projected climate impacts of aviation emissions in 2050 using two advanced General Circulation Models, GATOR-GCOM and CESM.[i] The study assessed radiative forcing, ozone disturbance, and changes to surface temperatures resulting from projected levels of aviation emissions in 2050. Baseline emissions computed by AEDT for 2006 were used to compare multiple future (2050) scenarios. The baseline scenario analyzed assumes no technological or operational improvements over time and results in projected emissions in 2050 that are approximately five times the emissions of 2006. Scenario 1 assumes technology improvements and therefore reduced fuel burn. Scenario 2 assumes the technology improvements used in Scenario 1, plus sustainable aviation fuels that have no sulfur and 50 percent less black carbon (BC) than conventional fuels. Scenario 2B assumes no technology improvements but does include sustainable aviation fuels with no sulfur and 50 percent less BC. Scenarios 1 and 2 result in projected emissions in 2050 that are 3 times higher than 2006. Finally, Scenario 3 assumes the same parameters as Scenario 2, plus higher water emissions from aviation engine exhaust.

The model results show a projected increase in radiative forcing between 12 to 90 megawatts/m^2, or 7 times the radiative forcing in 2006.[i] The upper limit of this range is considered unrealistically high as the baseline scenario is very conservative (assumes no technology or operational improvements). The models also show that radiative forcing is concentrated in the atmosphere over regions of high emissions (high air traffic), specifically over high traffic areas of Asia, Europe, and North America.

Results from Scenarios 1 and 2 show that the use of sustainable aviation fuels that reduce sulfur and BC will "significantly alter the future climate impacts of aviation"[i] though more research is needed to determine with greater certainty the impacts. This is because sulfur has a strong indirect cooling effect, while BC (or soot) has a warming effect. The study also found that increases in regional radiative forcing from aviation do not result in changes to regional surface temperatures. In other words, radiative forcing does not necessarily correlate with surface temperature changes where the forcing occurs.

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2.1.4 RESEARCH NEEDS

In order to holistically implement the vision of integrating adaptation planning, several research goals have been identified to help bridge the gap between what has been done and what needs to be completed. Building on the vision of the previous section, the following research needs have been identified:

- How to integrate airport resilience and climate change adaptation planning into:
  - Master planning
  - Day-to-day planning
  - Habits and understanding of stakeholders
  - Operations planning and coordination, leveraging, and integrating into existing mechanisms and plans focused on emergency preparedness
  - Staffing
  - Communication
  - Local adaptation planning
- Research and make recommendations on how to update infrastructure design criteria for airports to account for climate change. Conduct gap analysis in identifying potential design criteria updates based on climate change risks. Consider what design criteria need to be updated to account for changes/risks of climate change (airport-specific design criteria)
- Create a central, actively-updated repository for the following:
  - Identify and measure effectiveness of various risk and vulnerability assessment methodologies
  - Gather best practices for adapting to various climate change variables
  - Research on current adaptation strategies
  - Assess the effectiveness of adaptation strategies that have been implemented
  - Build on the work competed in the EU for adaptation planning to create a forum for sharing of information on resilience planning and adaptation methods

This could involve an update to the Sustainable Aviation Guidance Alliance (SAGA) database.

- Synthesize existing data relative to the costs of climate change on facilities. There are several reports, such as *ACRP Research Report 160*,[224] that examine extreme weather financial impacts but include a very limited data set for airports. Similar to the economic impacts of aviation reports completed as part of system plans, this research would be most useful if focused on aviation-specific costs. The numbers could be used nationwide for reports to help justify resilience planning and projects from a financial perspective. While national/international numbers exist, there is a need for aviation-specific data that can be used locally to promote and evaluate risks for airports.
- Identify funding, financing, and revenue generation options. Similar to the approach with renewable energy, identifying funding and financing options has been instrumental in furthering the use of these technologies. A similar need exists for resilience. Funding exists for developing countries in adaptation and resilience projects, but the aviation industry needs support to identify funding sources for adaptation and resilience planning for aviation projects. Examples of innovative funding mechanisms could include advanced microgrid capabilities that

can offer opportunities for transactive capabilities such as peak load avoidance, demand-response, and other revenue generation.

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2.2

Carbon Reduction and Management

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2.2.1 INTRODUCTION

Aviation's contribution to global carbon emissions was approximately 2 percent as of 2017. It is projected to grow as demands in travel and air freight increase, particularly in emerging markets.[225] In addition, while air carriers have decoupled their carbon emissions from the growth in number of passengers served and amount of cargo transported, the entire industry seeks to further reduce its carbon footprint and contribute to collective efforts to further mitigate climate change impacts.[226]

The majority of aviation-related carbon emissions come from aircraft; however, air travel can induce emissions from surface access (mainly via road vehicles travelling to/from airports) and activities on site at airports (e.g., heating and lighting of infrastructure and GSE). For airports, emissions on site are classified as scope 1, 2, or 3 based on the airport's control over the emissions. For example, scope 1 emissions are those emissions that come directly from the airport such as from the airport's own fuel use), whereas scope 2 emissions are the indirect emissions that come from the airport's purchase of electricity, heat, or steam. Scope 3 emissions are those emissions induced from activities at the airport, like the aforementioned emissions from vehicles coming to and leaving from the airport and emissions from aircraft.[227] This chapter focuses primarily on aircraft emissions, which are the bulk of the aviation-related carbon emissions, with some discussion of reducing emissions from ground transportation and equipment.

In 2009, the industry, through the Air Transport Action Group,[228] committed to three carbon reduction goals to: (1) improve average fuel efficiency 1.5 percent per year from 2009 to 2020, (2) keep growth carbon neutral from 2020, and (3) halve net aviation CO_2 emissions by 2050, relative to 2005 levels.[229] For their part, airports are also working to reduce their carbon footprints, and many have committed to becoming carbon neutral. For example, Dallas-Fort

Worth International Airport (DFW) and San Diego International Airport (SAN) have already been accredited as carbon neutral airports.[230]

The remainder of the section will discuss the actions industry has taken to reach its collective goals, the near- and long-term vision for reaching these goals, and the additional research needed to assist industry in achieving these goals. Additional resources are provided at the end of the section to provide readers with references containing greater details on the industry's efforts.

2.2.2 CURRENT STATE

The aviation industry has taken a four-pronged approach to fulfilling its carbon reduction goals noted above. To meet these targets, the industry is pursuing technological, operational, and infrastructure improvements as well as establishing a carbon offsetting mechanism to be used as a backstop to ensure success. Progress has been made in recent years in each of these categories as detailed below.

2.2.2.1 Advancements in Technology

Aircraft manufacturers and airlines have been working in recent years to reduce the aviation industry's carbon footprint. Because CO_2 emissions are directly proportional to fuel burn, these stakeholders have worked to improve fuel efficiency. Aircraft manufacturers have improved the fuel efficiency of their fleet offerings year over year by focusing on engine design as well as the weight of every aspect of the aircraft. In 2018, U.S. airlines carried 42 percent more passengers and cargo than in 2000 with only a 3 percent increase in total CO_2 emissions.[231]

In 2015, Boeing introduced the new 787-9s (the Dreamliner) with fuel-efficient engines that reduce CO_2 emissions by at least 20 percent compared to the aircraft they replaced.[232] In addition, manufacturers are replacing the traditional aluminum in the aircraft bodies with lighter weight carbon fiber and also offer lighter weight seats, cargo nets, and exterior paints for airline liveries to save on fuel burn. Reducing the weight of aircraft seats by 1 pound each saves nearly 7,000 gallons of jet fuel per year for a single-aisle aircraft. These fuel savings translate to approximately 65 metric tons of CO_2 reduced per year per plane.[233]

New aircraft designs have also resulted in reduced carbon emissions. Improved three-dimensional airflow modeling has enabled manufacturers to enhance aircraft aerodynamics. Similarly, the advent of composite materials enhances the aeroelastic efficiency of aircraft. These and other technological advancements spurred ICAO CAEP to agree to a CO_2 emissions regulatory standard for commercial aircraft in February 2016. This standard, resulting from 6 years of committed work by a task force of experts from governments, industry and non-governmental organizations, was endorsed by the ICAO Council and became effective in 2020. The CO_2 standard limits the amount of carbon emitted from aircraft and will ensure additional progress for new large aircraft designs from 2020 and for smaller aircraft (those below 19 seats) from 2023. The standard also applies to all existing aircraft designs rolling off the production line starting in 2023. Lastly, the standard includes a production cut-off date of 2028, meaning any aircraft that do not meet the standard much cease production in that year. In July 2020, the EPA issued proposed standards that match those adopted by ICAO for international airplane CO_2 emissions.[234] The EPA's Notice of Proposed Rulemaking, *Control of Air Pollution from*

Airplanes and Airplane Engines: GHG Emission Standards and Test Procedures, proposes GHG emission standards for certain new commercial airplanes, including large passenger jets.[235]

For their part, airlines are also looking at ways to increase the fuel efficiency of their fleets through technology. Many airlines have been retrofitting their aircraft wings with a hardware feature called a winglet. This blended wingtip device designed to reduce drag on aircraft wings saves up to 5 percent on fuel costs for single-aisle aircraft. As of 2018, the foremost manufacturer of winglet technologies estimates that it has saved 9 billion gallons of jet fuel or reduced CO_2 emissions by over 95 million tons worldwide.[236] Similarly, airlines have replaced pilots' paper navigational charts with tablets. Rather than lugging these bulky and heavy maps, many airline pilots are now using tablets to access navigational charts, cutting 80 pounds of paper loaded onto aircraft, saving 576,000 gallons of fuel per year.[237]

Since the last edition of this E-Circular, the aviation industry has also been investing in the commercial advancement of sustainable aviation fuels as another means to reduce carbon emissions. SAF are jet fuels produced from alternative sources of hydrocarbons rather than conventional petroleum. 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. As detailed in Section 1.3.2 the ASTM has approved the use of seven alternative, bio-based SAF,[238, 239] including:

- Alcohol to Jet Synthetic Paraffinic Kerosene, created from isobutanol derived from sugar, corn and wood waste products
- Synthesized Iso-paraffins, converts sugar to jet fuel
- Hydroprocessed Esters and Fatty Acids (HEFA) Synthetic Paraffinic Kerosene), made from fats, oil and grease
- Fischer-Tropsch Synthetic Paraffinic Kerosene
- Fisher-Tropsch Synthetic Kerosene with Aromatics (both Fisher-Tropsch Synthetic Kerosene with Aromatics and Fisher-Tropsch Synthetic Kerosene with Aromatics with Aromatics use biomass such as woody biomass and municipal solid waste)
- Catalytic Hydrothermolysis Jet using waste oils
- Synthesized paraffinic kerosene from hydrocarbon-hydroprocessed esters and fatty acids

As of June 2018, more than 130,000 flights have been performed throughout the world using SAF.[240] While SAF has yet to become cost competitive with petroleum-based jet fuel, airlines are still voluntarily purchasing SAF for use in commercial flights. In March 2016, United Airlines became the first airline in the world to introduce SAF into normal business operations on daily flights from LAX using hydroprocessed vegetable oils and animal fats. World Energy (formerly AltAir Fuels) produces the SAF supplied to LAX at its Paramount, CA facility, which has the capacity to produce 38 million gallons of SAF per year.

Thirteen commercial-scale SAF production facilities are either under construction or planned for construction as of June 2018. These facilities should be online by 2022 and add an additional 925 million gallons per year of SAF production capacity to the 57 million gallons of commercial SAF production capacity online today. These facilities will use a variety of feedstocks like municipal solid waste, sugars, wood waste, and fats, oils and grease (FOG) to produce a variety of fuel types including jet fuel. Importantly, the facilities will be geographically diverse to ensure a wide array of markets have access to SAF.[241]

The major hurdle to SAF deployment is price parity with conventional jet fuel. While progress has been made to ramp up SAF production capacity, many of the production facilities have the capacity to also produce biodiesel, which under current market conditions commands a higher price and has a larger market.[242] As a result, actual SAF production continues to be limited, and SAF that is produced is flowing to states where financial incentives exist, like California and Oregon, each of which have clean fuel programs that provide credits for SAF use.

The SAF industry currently has seven production pathways associated with various feedstocks approved through the ASTM standards-setting body. The planned facilities will use one of these seven production pathways, but there are also several additional proposed pathways that are making their way through the ASTM qualification process known as D4054. While several of these pathways rely on the feedstocks mentioned above, like FOG and sugars, they are also exploring new feedstocks, like algae. In addition, there are also a number of pathways that industry is considering but that have not yet entered the D4054 process. These approaches rely on biological (e.g., fermentation or microbial conversion) or thermochemical (e.g., pyrolysis, hydrothermal liquefaction, or catalytic conversion) processes to convert feedstocks into the chemical components of jet fuel.[243]

On the ground, airlines and airports are working together to reduce their carbon footprints by converting diesel-powered GSE and vehicle fleets to all-electric equivalents where economically practicable and commercially available. While airlines are usually the owners of electric GSE (eGSE), airports often own the charging infrastructure airlines use to charge the eGSE batteries. For years, airports have been leveraging federal funds through the FAA Voluntary Airport Low Emissions (VALE) program[244] to install GSE charging stations. Airlines have recently been taking advantage of funds available through the Volkswagen “Dieselgate” settlement to purchase eGSE.[245,246] For example, United Airlines, Southwest Airlines, and JetBlue were awarded a combined $5.7 million to convert over 130 pieces of GSE to all-electric equivalents in Nevada.[247] Similarly, airports are converting their own vehicle fleets to all-electric and providing charging stations in public spaces to facilitate passenger use of electric vehicles (EV) for their transportation to/from the airport. Together, the airports and airlines are deploying eGSE and EV across the country, reducing not only their carbon emissions but also emissions of other local air pollutants.

2.2.2.2 Operational Improvements

In addition to the technological advancements assisting the industry in managing aviation’s carbon footprint, the sector is also focused on achieving operational improvements to reduce emissions. In particular, airlines have deployed techniques like ground power unit (GPU) and pre-conditioned air (PCA) usage, improved maintenance programs, and single engine taxiing to reduce their CO_2 emissions. Conventionally, when an aircraft is parked at the gate, it continues to burn jet fuel through its APU to keep the lights on and the heating, cooling, and ventilation system running between flights. To reduce carbon emissions, airlines can use GPU and PCA to power and cool/heat the aircraft while at the gate. Not only does this cut down on fuel burn for the airlines, but GPU and PCA rely on the airport’s electric grid, which is a cleaner and more efficient source of energy than conventional jet fuel.

Another operational technique the industry is using to reduce emissions is improved maintenance programs. A poorly maintained aircraft is an inefficient aircraft. Aircraft manufacturers detail maintenance best practices for airlines to use to ensure aircraft engines maintain optimal efficiency. This not only contributes to less aircraft being taken out of service for unexpected maintenance issues but also reduces carbon emissions.

A final, simple, yet important, operational improvement airlines employ to reduce their carbon emissions is single engine taxiing. Historically, aircraft would use both jet engines when taxiing on the airport tarmac, but as airline pilots have become more fuel conscious many now use single engine taxiing on arrival, which cuts taxi fuel burn by approximately 37 percent.[248]

2.2.2.3 Infrastructure Improvements

The third prong of the industry's efforts to manage its carbon emissions is infrastructure improvements. Air Navigation Service Providers (ANSP) manage air traffic patterns across the world. As technological advances in global positioning systems have come online, ANSPs have been able to replace the traditional vector flight paths (i.e., point-to-point flying) with global positioning system (GPS)-based flight paths, which allow for more efficient flying. This GPS-based system of flying, known as NextGen, not only allows aircraft to travel the most efficient path geographically between two city-pairs, but it also allows aircraft to fly more efficiently in relation to each other. It also allows ANSPs to update pilots to change the speed at which they are flying well before reaching their destination so that they arrive at their destination when they will be able to land. This operational efficiency reduces the need for aircraft to circle in the air space above a crowded airport and needlessly burn additional jet fuel. That reduction in fuel burn translates into reduced CO_2 emissions. Similarly, this next generation of air traffic management improves efficiencies for takeoff allowing aircraft to avoid idling on tarmacs and again saving fuel and reducing CO_2 emissions.

Because NextGen has moved flight paths in some instances and concentrated the paths aircraft fly, there has been negative public reaction in some cities at NextGen deployment. In certain instances, NextGen procedure implementation has been delayed or changed as a result.[249]

Airports are also making infrastructure improvements. In 2009, ACI-Europe launched ACA, which follows the World Resources Institute/World Business Council for Sustainable Development's Greenhouse Gas Protocol Corporate Standard, which delineates emissions based on the airport's control over their production. Through this program, airports commit to first accounting for all their direct and indirect GHG emissions, defined by scope as described above. Airports can choose to simply do this step, attaining Level 1 certification. Based off this inventory of GHGs, airports can also then work to reduce their direct emissions, attaining Level 2 certification, or go even further to promote and support reductions in their indirect emissions, attaining Level 3 certification. To date, 55 airports have signed up for the ACA in North America, two of which have already achieved carbon neutrality, or Level 4 certification, as noted above.[250]

2.2.2.4 Carbon Offsetting

In addition to the carbon reduction measures already noted, the industry, through ICAO, agreed to a global market-based measure for international aviation. The ICAO Assembly adopted CORSIA in 2016.[251] Under CORSIA, airlines will be required to buy carbon offsets to compensate for their growth in CO_2 emissions starting in 2021. Starting in 2019, all airlines operating international flights began monitoring and reporting their fuel consumption on their international flights to their national authorities. CORSIA will operate on 3-year compliance cycles, so every 3 years operators will have to demonstrate that they have met their offsetting requirements. From 2021 to 2026, flights between countries that have voluntarily agreed to participate in this "pilot phase" will be subject to the offsetting requirements. Starting in 2027, all international flights will be subject to CORSIA with a few exceptions for less developed countries, small island developing states, landlocked developing countries, and countries with particularly low aviation activity.[252] As of July 2019, 81 countries, including the United States, representing nearly 77 percent of all international aviation activity, have volunteered to participate in the pilot phase of CORSIA.[253]

2.2.3 FUTURE VISION

The goals and future vision of the aircraft industry as they relate to deeper CO_2 emission reductions can be summarized by the following:

- Continued collaboration among interested stakeholders to meet the ICAO goals
- Petroleum-based, price parity for SAF
- Achieving long-term SAF production levels that can contribute significantly to the industry's 2050 goal of 50 percent reduction in net CO_2 compared to 2005 levels
- Significant research and development of hybrid and electric battery aircraft technologies
- Commercial deployment of electric taxiing
- Further improvements in engine efficiency, aerodynamics, lightweight materials and structures
- Research and development of new aircraft configurations to minimize CO_2 and other air pollutant emissions

2.2.4 RESEARCH NEEDS

While substantial progress has been made in recent years to understand and mitigate carbon emissions from the aviation sector, more research is needed. Particular research needs can be summarized by the following:

- SAF for turbine aircraft need to continue to be assessed for potential reductions in emissions of GHGs.
- Additional techno-economic analysis of SAF is needed to assess the potential for SAF to reach price parity with petroleum-based jet fuel. Analyses should include assessments of drivers like carbon offset crediting that could create a tipping point for SAF commercial deployment.
- APU emissions profiles need to be further assessed. APU efficiencies have been improved in response to the changing price of fuel. The exhaust models for the newer APUs need to be studied and updated.
- Updated emission factors for non-aircraft emission sources at airports, such as GSE and motor vehicles, need to be developed. As electric vehicles become more prevalent, the emissions modeling for those vehicles will also need to consider the effects of shifting the

burden of emissions from the airport to the power generation and delivery companies. Note that EPA released the latest version of the MOtor Vehicle Emission Stimulator, or MOVES3, in November 2020 that includes the latest vehicle emissions factors and can be applied to airport settings.[254]

- Emission estimates and emission factors for aircraft landing emissions associated with brake and tire wear need continued research and development.
- Recent airport data regarding the impacts of carbon reduction due to airport operations need to be synthesized. The analysis could include the practices of idling vehicles on the roadways or ramps, the inclusion of carbon impact due to airport buildings and operations, the choices of materials for airport buildings/roadways/structures that reduce or sequester carbon, the choices of materials inside the terminals that reduce or sequester carbon, the effects of incentives offered to airport vendors that reduce their carbon footprint, the land management practices to reduce or sequester carbon at airports, and the use of telematics to understand airport fleet operational characteristics and related emissions.
- Ways to include the carbon reduction or carbon 'cost' in airport decision-making models and methods for structures, buildings, and roadways should be pursued.
- Planning process and organizational behavior tools should be analyzed for their potential impact to reducing the sector's carbon emissions.

NOTES

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2.3 Aircraft Technology and Operations

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2.3.1 INTRODUCTION

Aviation is integral to the global economy and transportation system. Despite ongoing short-term market volatility, aviation demand and aircraft operations are projected to increase in the future. Growth in aviation may lead to increased environmental impacts, necessitating the timely implementation of well-informed, optimally balanced mitigation measures. The evolution of modern, more efficient airframes and engines has produced significant aviation fuel, emissions, and noise reductions on a per-flight basis historically (as depicted in **FIGURE 2-1 and FIGURE 2-2**) and will drive more reductions in the future. Achieving more efficient aircraft operations is another critical element for reducing fuel and emissions from aviation. Both the U.S. federal government and the aviation industry are actively working to advance cleaner, quieter, and more efficient aircraft technology and aviation operations. This section focuses on aircraft technology and operations as a sustainable solution to addressing aviation environmental challenges, including a discussion of the current state, future vision, and research needs.

2.3.2 CURRENT STATE

Technologies that reduce noise and emissions are regulated at the vehicle level as a part of airworthiness certification. These environmental standards are harmonized internationally through ICAO CAEP. On October 4, 2017, the Federal Register published a new noise standard—known as Stage 5—for newly certified large airplanes.[255,256] The noise standard applies to large jets manufactured after 2017 with a maximum takeoff weight greater than or equal to 55,000 kilograms (kg) and to lower weight aircraft after 2020. Stage 5 is in alignment with the ICAO Chapter 14 noise standard, adopted July 14, 2014. In 2016, ICAO CAEP reached an agreement in adopting an aircraft CO_2 emissions standard.[257] The primary aims of the aircraft CO_2 standard are to incentivize faster development of fuel-efficient technology and serve as a basis for ensuring that less efficient aircraft technologies are eliminated over time. Standards also exist for landing and takeoff NO_X emissions and are in development for non-volatile particulate matter.[258]

Apart from the standard-setting process, the U.S. federal government is leading a number of efforts and collaborating with the aviation industry to mature new technology that results in increased fuel efficiency and reduced noise and emissions. Federal government actions in the United States to improve aircraft and engine technology are carried out by FAA, NASA, and the

Department of Defense, among others, and are coordinated through the *National Aeronautics Research and Development Plan*.[259]

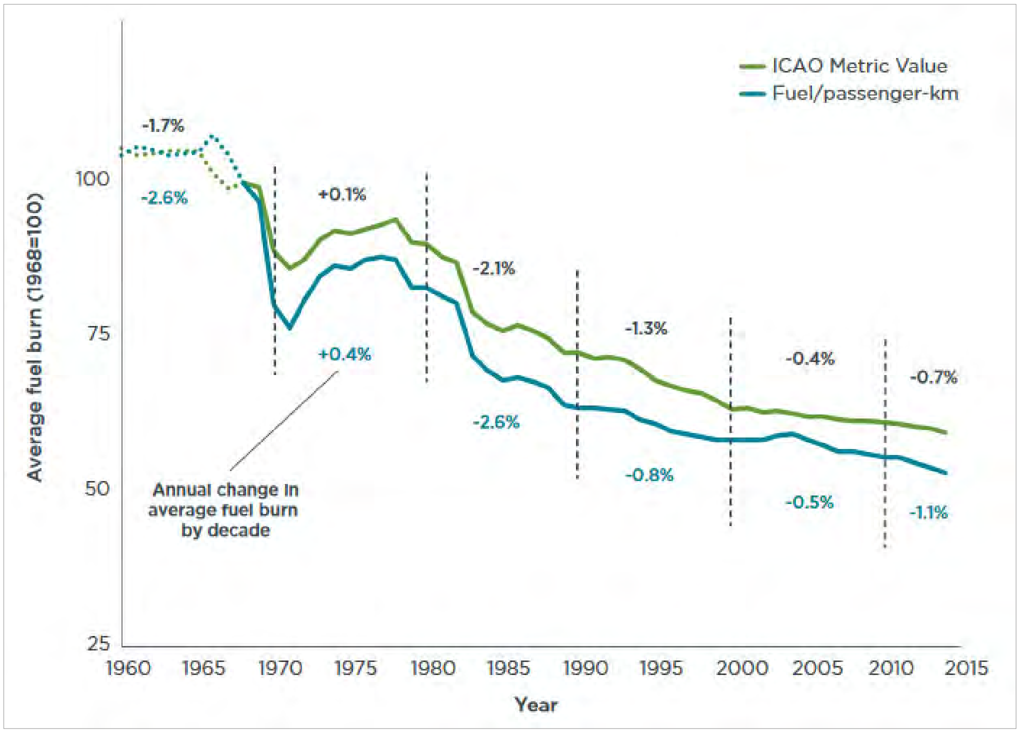

FIGURE 2-1 Average fuel burn for new commercial jet aircraft, 1960–2014.[260]

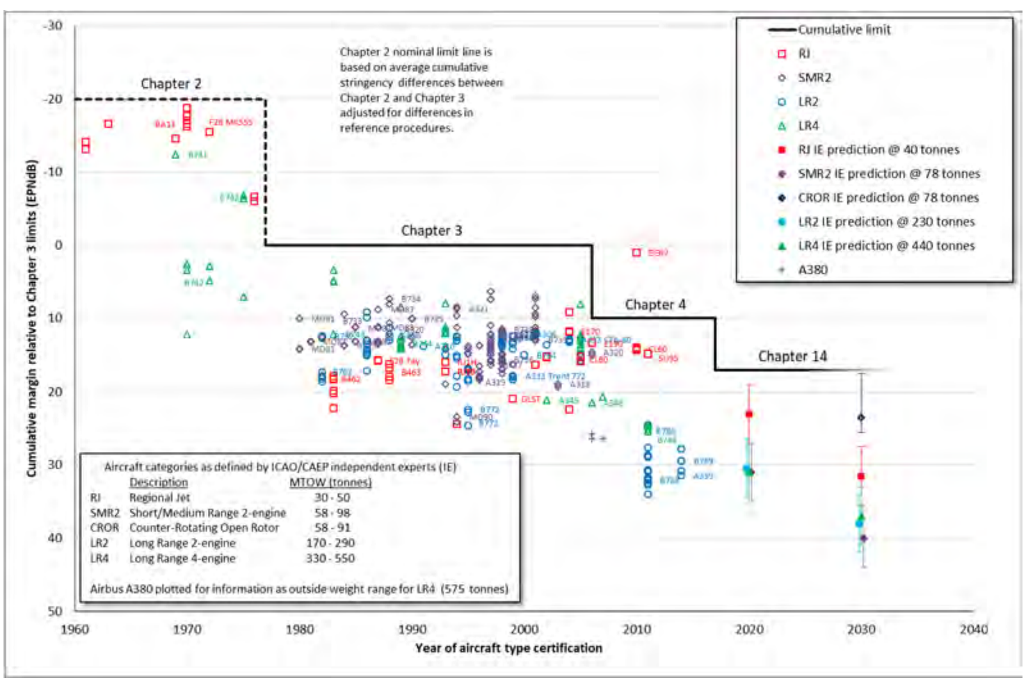

FIGURE 2-2 European Aviation Safety Agency (EASA) certified noise levels versus Chapter 3 limit.[261]

As briefly discussed in Section 1.2.1, the CLEEN Program is the FAA's principal environmental effort to accelerate the development of new aircraft and engine technologies and advance sustainable alternative jet fuels. The CLEEN Program is a collaborative partnership with aviation manufacturers and is a key element of the NextGen strategy, which is discussed further below, to achieve environmental protection that allows for sustained aviation growth. With the support of the CLEEN Program, the aviation industry is able to expedite the integration of cleaner and quieter technologies into current and future aircraft. CLEEN helps accelerate technologies through a crucial phase in their maturation, culminating in full-scale ground and flight test demonstrations that show readiness for product implementation.[262]

The FAA initiated CLEEN, which requires a 1:1 minimum cost share match from industry, in 2010 for a period of 5 years from 2010 to 2015. Over the 5-year course of the program, several technologies have been tested and are in use today. FAA awarded 5-year contracts to nine companies (totaling $100 million in federal investments) for the research and development of technologies that will help reduce noise, emissions and fuel burn, and advance the development of sustainable alternative jet fuel.[263]

With the successful execution of the initial CLEEN effort, the FAA initiated the second phase of the CLEEN Program to run from 2015 to 2020.[264] It is a goal of the CLEEN Program for these technologies to be on a path for introduction into commercial aircraft within 5 years of conclusion of each project. The quantitative aspirational goals for reductions in fuel burn, emissions, and noise for CLEEN I and CLEEN II are shown in **TABLE 2-1**.

TABLE 2-1 Summary of CLEEN I and CLEEN II Aspirational Reduction Goals for Fuel Burn and Emissions[82]

Goal Area	CLEEN I Goals (2010-2015)	CLEEN II Goals (2015-2020)
LTO NOx Emissions (Below CAEP/6)	-60 percent	-75 percent
Aircraft Fuel Burn	-33 percent	-40 percent

Some of the technologies developed during the initial CLEEN Program have already begun to enter the aviation system. The FAA works with selected industry partners under CLEEN through cost-sharing where companies in the program match or exceed funding provided by the FAA. Specifically, these companies are developing technologies that will reduce emissions and fuel burn and enable the aviation industry to expedite integration of these technologies into current and future aircraft. The CLEEN III Program is included in FAA's Fiscal Year 2020 enacted budget.[265]

Several key projects and demonstrations being conducted under CLEEN II include:[266]

- Aurora Flight Sciences is developing and demonstrating composite airframe technologies that will enable an unconventional aircraft configuration that could reduce fuel burn, emissions, and noise.
- Boeing is developing and demonstrating advanced aircraft wing technologies that could reduce aircraft fuel burn by up to 3.5 percent.[267]

- The team of Delta Tech Ops, MDS Coating Technologies and America's Phenix is developing and demonstrating a protective leading-edge coating for gas turbine engine fan blades.
- GE Aviation is developing three aircraft technologies and undertaking one sustainable aviation fuel project. More Electric Systems and Technologies for Aircraft in the Next Generation (MESTANG) is an integrated aircraft power system designed to support future "more-electric" aircraft architectures. The MESTANG technologies under CLEEN II may reduce fuel burn by up to 3 percent for single-aisle aircraft.
- Pratt & Whitney is developing and demonstrating technologies for the engine compressor and turbine to improve engine thermal efficiency and reduce fuel burn of the Pratt & Whitney GTF engines.
- Rolls-Royce's advanced Rich-Quench-Lean combustion system employs advanced fuel injection and mixing technologies that will provide significant emissions reduction while simultaneously enabling the increase in Turbine Entry Temperature required by advanced engine cycles.
- Rohr, Inc./UTC Aerospace Systems is developing and demonstrating a thrust reverser for a short, integrated engine fan duct that enables ultra-high bypass quiet and efficient engines.

NASA continues to push research and exploration of environmentally sustainable aviation technologies. NASA does this primarily through its Advanced Air Vehicles Program (AAVP) and Integrated Aviation Systems Program (IASP), which include the Advanced Air Transport Technology (AATT), Commercial Supersonic Technology, and Transformational Tools and Technology projects. These projects focus on new vehicle technologies that have the potential to significantly reduce aviation's impact on the environment.

AAVP and IASP both conduct research on new vehicle technologies that will have a significant impact on reducing emissions. NASA does not build engines or engine components, but rather, NASA programs and research generate advanced technologies and knowledge. Typically, 5 to 10 years after the conclusion of a NASA program, industry will build on NASA's research results and integrate the associated knowledge into commercial products. One example research focus area for the AATT Project is the development of aerodynamic and structures technologies that enable an increase in the optimal wing aspect ratio by 50 to 100 percent, reducing weight and drag, while preserving structural safety and flight control. In this vein, NASA is researching a truss-braced wing, which is a future generation transport aircraft concept that is designed to be aerodynamically efficient by employing a high aspect ratio wing design.

On the operations side, the FAA is implementing a comprehensive, multi-year modernization of the NAS known as NextGen.[268] While the benefits of NextGen are many and go well beyond the environment, among the key elements of NextGen are reducing delays, establishing more precise routes, and improving overall efficiency of the NAS, all of which can contribute to reduced fuel burn and emissions. Similar work to modernize air traffic management (ATM) systems is ongoing in Europe through the Single European Sky ATM Research Joint Undertaking (SESAR JU).[269] In 2011, the United States and EU initially signed a Memorandum of Cooperation to ensure harmonization and interoperability over the full life cycle of the two programs. This was further extended and expanded in 2015 with a Letter of Intent on Air Traffic Management Modernization to ensure that NextGen and SESAR collaboration and research continue.[270]

Implementation of NextGen will allow for more efficient aircraft operations, increased capacity, and reduced fuel burn. The FAA has finished implementing most of the foundational infrastructure that will enable critical NextGen capabilities. The two major automation platform upgrades being put in place are the Standard Terminal Automation Replacement System and En Route Automation Modernization. In conjunction with Automatic Dependent Surveillance–Broadcast, which provides improved surveillance accuracy for precise, satellite-based aircraft position tracking, the majority of the surveillance and navigation infrastructure is in place to enable the transition to satellite-based navigation and surveillance as the FAA's primary means of service delivery.

The fundamental infrastructure upgrades NextGen is delivering are nearly complete. These are planned to be leveraged to move the NAS to an operational vision of trajectory based operations, or TBO. TBO is an air traffic management method for strategically planning, managing, and optimizing flights throughout the operation by using time-based management, information exchange between air and ground systems, and the aircraft's ability to fly precise paths in time and space. This concept leverages the navigation, communication, surveillance, and information exchange infrastructure that NextGen has put in place, and completes enhancements to enable more strategic management of aircraft by time, as opposed to static distance-based restrictions. TBO will improve the efficiency, predictability, flexibility, and throughput of the NAS.

The FAA and industry collaborate primarily through the NextGen Advisory Committee (NAC), a 28-member federal advisory group that advises on policy-level issues to implement NextGen. Through the NAC, the FAA and industry have produced a plan to deliver high-priority NextGen capabilities in the near-term across five focus areas: performance based navigation, data comm, multiple runway operations, improved surface operations, and improving operations in the Northeast corridor.[271] NextGen initiatives are resulting in benefits to airlines, passengers, the FAA and other users. The FAA estimates that NextGen's implemented improvements accrued $7B in benefits to industry and society from 2010 through 2019, consisting of $1.51M in decreased aircraft operating expenses, $4.162M in decreased passenger travel time, and $0.366M in safety benefits.[272]

The NASA Airspace Operations and Safety Program (AOSP) conducts a broad range of research focused on improving the performance and efficiency of the air transportation system. This research focuses on various phases of operations including surface, terminal, and en route. AOSP develops and explores fundamental concepts, algorithms, and technologies to increase throughput and efficiency of the NAS safely. The program works in close partnership with the FAA and the aviation community to enable and extend the benefits of NextGen. Integrated demonstrations of these advanced technologies will lead to clean air transportation systems and gate-to-gate efficient flight trajectories. The program is on the leading edge of research into increasingly autonomous aviation systems, including innovation in the management of UAS traffic and other novel aviation vehicles and business models. The program is also pioneering the real-time integration and analysis of data to support system-wide safety assurance, enabling proactive and prognostic aviation safety assurance.

2.3.3 FUTURE VISION

While innovative concepts and new entrants may transform air transportation in the future, the aviation community expects that large (single- and twin-aisle), long-haul subsonic airplanes will continue to provide the bulk of global air transportation in the near- and mid-term. Both NASA and the National Academies of Sciences, Engineering, and Medicine emphasize the need for the introduction of energy-efficient and quiet community-friendly technologies in order to enable sustainable growth in this sector.[273,274] The 2016 National Academies report identifies advances in aircraft-propulsion integration and improvements in gas turbine engines as key areas of focus for propulsion and energy system technologies. Performance improvements in these areas must be pursued while continuing to reduce development, manufacturing, and operational costs without compromising safety.[275]

NASA air vehicle research is segmented into technologies for near-term (2015-2025), mid-term, (2025- 2035) and far-term (>2035) generations of vehicles with increasing levels of efficiency and environmental performance.[276] **TABLE 2-2** shows NASA's targeted noise, emissions, and fuel consumption metrics for projected subsonic vehicles in these timeframes. The U.S. federal government, industry, and academia are working together to explore and advance vehicle concepts and enabling technologies in pursuit of these goals.

TABLE 2-2 NASA Targeted Improvements in Subsonic Transport System-Level Metrics[277]

Technology Benefits	Technology Generations (Technology Readiness Level=5-6)		
	Near-term 2015-2025	Mid-term 2025-2035	Far-term Beyond 2035
Noise (Cumulative below Stage 4)	22-32 dB	32-42 dB	42-52 dB
LTO NO_x Emissions (Below CAEP 6)	70-75%	80%	>80%
Cruise NO_x Emissions (Relative to 2005 best in class)	65-70%	80%	>80%
Aircraft Fuel/Energy Consumption (Relative to 2005 best in class)	40-50%	50-60%	60-80%

The approach forwards both near-term, emergent technologies as well as longer-term, transformational concepts. For the latter, an example promising area of work is the development of electrified aircraft-propulsion concepts. All electric and hybrid electric architectures rely on batteries to provide energy for propulsion during one or more phases of flight. The turboelectric propulsion concept employs gas turbines to drive electrical generators that power electric motors, which in turn drive propulsors (e.g., fans or propellers). Combined with other technologies, turboelectric systems could potentially reduce fuel burn by up to 20 percent or more compared to aircraft in service today. Research is ongoing to develop core technologies that meet the necessary specific power, weight, and reliability parameters that could enable a successful commercial deployment.

Operationally, on top of the NextGen foundation, the FAA is developing and deploying Decision Support Systems that enable air traffic controllers to make informed, effective decisions in rapidly changing environments. These tools include the Traffic Flow Management System, Time Based Flow Management, and Terminal Flight Data Manager. Together these components provide integrated, responsive, and collaborative traffic flow management solutions that maximize efficiency and reduce delays through each phase of flight. Looking ahead, these and other components of NextGen that are still in development will work in concert to transition air traffic control from a system based on knowing where an aircraft is at any given moment to one based on knowing where an aircraft will be at critical points along its flight path for improved capacity and efficiency. Using TBO leads to reduced environmental impact and fuel burn due to uninterrupted ascents and descents, user-preferred routing, and reduced excess times in queues and holding patterns at major airports.[278,279]

2.3.4 RESEARCH NEEDS

Government and industry research and development is focused on the technologies with the greatest potential for impact and market penetration. A selection of ongoing areas of research that may provide noise, fuel, and or emissions benefits includes the following:

- High-temperature materials in gas turbine engine cores for improved thermal efficiency and/or weight reduction
- Enhanced gas turbine engine core thermal efficiency in combination with reduced core size for weight reduction
- Advanced, ultra-efficient propulsion systems
- Enabling high bypass ratio and low fan pressure ratio gas turbine aero engine designs
- Airframe and engine weight reduction via advanced materials and construction
- Airframes with high levels of aerodynamic performance (whether by component design or via flow control) and innovative approaches to noise reduction
- Enhanced airframe and propulsion system integration
- Integration of aircraft and engine control software or control hardware packaging
- More electrified aircraft, including all electric, hybrid electric, and turboelectric systems

Research to understand and manage the environmental impacts of new entrants, including supersonics, UAS, and commercial space vehicles, will be critical for certification and sustainable introduction into the airspace system. Continued advancement of methods and tools for modeling, simulation, and testing is also necessary to reduce development costs and improve system performance.

The research needs for a fully deployed NextGen system are aligned with the research needs for more efficient aircraft operations, as the latter is a fundamental goal of the former. Improved predictability and use of airspace capacity leads to more optimal, unimpeded aircraft trajectories, which reduces fuel burn and emissions. A potential gap area to address are the noise consequences of more precise flight paths created by advanced, satellite-enabled air navigation systems. Research is ongoing across government, industry, and academia to identify operational opportunities to mitigate the impact of aviation noise on communities. One venue where this work is being carried out is ASCENT,[280] a leading aviation cooperative research organization with a broad portfolio of contributions. On this topic, ASCENT research is contributing to improved modeling and identification of advanced operational concepts with the potential to reduce aviation noise impacts.[281]

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3

Processes and Tools for Implementing Sustainable Solutions

3.1

Environmental Review Under the National Environmental Policy Act

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3.1.1 INTRODUCTION

The environmental review and resource management processes in the aviation system consist primarily of reviews conducted under NEPA.[282] NEPA requires all federal agencies to "utilize a systematic, interdisciplinary approach which will ensure the integrated use of the natural and social sciences and the environmental design arts in planning and in decision making…" NEPA established a broad national framework to protect the environment and requires federal agencies to consider the environment prior to undertaking a major federal action with significant impacts to the environment. NEPA serves as an "umbrella" law encouraging an integrated review with other environmental laws. Ensuring a truly interdisciplinary approach is challenging because the responsibilities for planning, designing, and building aviation infrastructure are divided among many public and private agencies and involve diverse technical disciplines. The following sections discuss the research needs in these areas.

3.1.1.1 Environmental Review and Management

NEPA is a decision-making process that consists of identifying needs, examining alternatives to meet those needs, evaluating environmental impacts of the alternatives, and selecting a preferred alternative. Ideally, this process ensures that, as NEPA requires; "…environmental amenities and values may be given appropriate consideration in decision-making along with economic and technical considerations."

While the FAA is ultimately responsible to ensure that environmental values are given appropriate consideration in planning for the NAS, the responsibilities for identifying the system needs, and planning for improvements, fall outside of the FAA. In addition, these activities are typically the responsibilities of technical experts in airspace and airport design whose objectives are to optimize the economic and technical performance of the system.

The FAA exercises its responsibilities under NEPA by reviewing federal actions under its jurisdiction. Such reviews include revisions to the 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. The time to complete NEPA reviews has been under scrutiny by Congress, the media, federal and state agencies, and the public.

Federal agencies, including the FAA, have implemented NEPA through orders and directives that require compliance with numerous other laws, regulations, and executive orders. The FAA collectively termed these as “special purpose laws.” FAA Order 1050.1F, Environmental Impacts: Policies and Priorities, serves as the FAA’s policy and procedures for NEPA compliance and CEQ implementing regulations. FAA Order 1050.1F applies to, but is not limited to, “grants, loans, contracts, leases, construction and installation actions, procedural actions, research activities, rulemaking and regulatory actions, certifications, licensing, permits, plans submitted to the FAA by state and local agencies for approval, and legislation proposed by the FAA.” [283]

The FAA Order 1050.1F Desk Reference lists 65 special purpose laws. While NEPA imposes procedural requirements, meaning that following the established procedures for NEPA is all that is required, some special purpose laws impose substantive requirements that can limit the ability of the FAA to approve actions that conflict with special purpose laws. In addition to these 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.

Although the NEPA process itself is relatively straightforward, the need to integrate multiple disciplines and meet the requirements of numerous federal and state special purpose laws causes many to believe that the effort needed to comply with NEPA is excessive. It is widely believed that the NEPA process could be more efficient, while still achieving the underlying purposes of NEPA.

FAA last updated its overarching procedures for implementing NEPA in 2015, which were presented in FAA Order 1050.1 *Environmental Impacts: Policies and Procedures*. The FAA identified several issues that were addressed through the update of this Order (FAA Order 1050.1F), including the following:

- The revision reorganized and revised 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. FAA Order 1050.1F also includes updates to reflect FAA’s NextGen capabilities and terminology. The Order includes a Desk Reference to complement FAA Order 1050.1F and provide explanatory guidance for environmental impact analyses.
- As part of FAA Order 1050.1F, the FAA expanded and updated the list of categorical exclusions and actions that typically require environmental assessments (EA) and environmental impact statements (EIS) to better reflect its past experiences and ensure the appropriate review is being conducted.
- The updated FAA Order 1050.1F incorporated recommendations and approaches from several guidance documents issued by either FAA or the CEQ to help clarify the NEPA process and FAA procedures. For example, the FAA issued a guidance memorandum to focus the assessments in EAs. This issue was not limited to the FAA; CEQ issued similar guidance entitled Improving the Process for Preparing Efficient and Timely Environmental Reviews under NEPA (March 6, 2012).[284]

Airport operators are finding that their internal processes for project planning and development often are not always fully integrated with NEPA process requirements. This can lead to environmental considerations not being considered upfront, resulting in project delays 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 further delay the project until requisite project data is available. Protracted environmental documentation can impede needed airport improvements and development, increase costs, and further polarize the relationship of the airport operator with regulatory agencies and airport neighbors. FAA guidance on the development of master plans and NEPA addresses these issues; however, a synthesis of airport practices investigating the effectiveness of these existing guidance documents may be useful.

Public perception of the NEPA process is that it 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. The resultant public opposition and litigation on environmental grounds adds time and increases the uncertainty of the environmental review process. The FAA has issued guidance on public involvement in the various planning processes preceding NEPA; however, a synthesis of airport practices in implementing this guidance may be useful.

As noted earlier, 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 in the FAA, and could involve airport operators, aircraft operators and tenants, local land use officials, and the public. While NEPA, CEQ regulations, and FAA guidance provide for "scoping" or other stakeholder coordination early in the process, further investigation into effective coordination could enhance the efficiency and acceptance of the NEPA process.

Practitioners have experienced differences in the environmental review process depending on the project location. A synthesis of best practices across regions could identify steps to achieve consistent, similar approaches. As noted above, FAA guidance addresses stakeholder coordination, and substantial efforts have been made to obtain agency buy-in at the start of the NEPA process. The synthesis could include practices used for effective stakeholder coordination, as well as successful efforts to obtain agency buy-in at the start of the NEPA process.

The perception and reality of noise, air pollution, incompatible land development, water quality, traffic congestion, and other environmental impacts, along with the level of trust or confidence in analyses of these effects, must be considered when assessing the effectiveness of environmental review processes. These considerations drive political, legal, and other decisions that affect the ability to upgrade and expand the aviation system in a timely manner. Similarly, some decisions regarding aviation have potential environmental effects that may or may not be fully consistent with federal, state, and local goals. Increasingly, airports, airlines, and manufacturers are examining proactive environmental or sustainability management approaches to meet business or policy objectives that extend beyond strict regulatory compliance. Studies of the effects of public perception and reaction on environmental review practices, as well as the interaction of the environmental process with environmental compliance requirements, are critical to addressing these issues. In addition, a follow-up to *ACRP Research Report 209* could provide for additional investigation of the integration of sustainability into the environmental process.

3.1.2 CURRENT STATE

In recent years, the aviation industry, government agencies, and Congress have focused on issues at congested airports and inefficient airspace system and flight operations. In response, government and industry entities have increased their efforts to evaluate the effectiveness of current environmental processes within the aviation context and to identify means of achieving the goals of environmental requirements. NEPA practitioners have noted that often there is a disconnect between the work in project planning and the environmental review process. Earlier consideration of environmental issues during the planning process will help streamline the overall NEPA compliance process.

Citizens complain about the length and writing style of NEPA documents; these documents can be repetitive, overly technical, and filled with “jargon.” Despite efforts to improve the process, few large airport improvement projects have been undertaken in recent years; streamlined NEPA process improvements remain untested and unlikely to have taken hold. Therefore, a continued need exists to identify additional improvements to increase the efficiency, maintain the overarching goals of environmental consideration and disclosure, while striving to reduce the timeline associated with NEPA compliance.

Recently, the FAA published several guidance documents aimed at improving both the technical review process and community engagement. These include:

- Section 106 Handbook: How to Assess the Effects of FAA Actions on Historic Properties Under Section 106 of the National Historic Preservation Act
- Community Involvement Manual which provides guidance on methods to involve the public in planning and environmental review processes[285]
- Updated agency wide NEPA Guidance Order 1050.1F Environmental Impacts: Policies and Procedures[286] and associated Desk Reference[287]
- FAA Order 1050.1 Guidance Memo “Guidance for Implementation of the Categorical Exclusion in Section 213(c)(2) of the FAA Modernization and Reform Act of 2012,” designed to expedite the review of certain air traffic procedures being implemented as part of NextGen[288]

In August 2017, the president signed Executive Order 13807, *Establishing Discipline and Accountability in the Environmental Review and Permitting Process for Infrastructure Projects*, which is designed to improve the delivery of federal projects.[289] The Office of Management and Budget and CEQ issued a memorandum to all federal agencies titled “One Federal Decision Framework for the Authorization Process for Major Infrastructure Projects Under Executive Order 13807.”[290] The Executive Order 13807 and framework require federal agencies to process environmental reviews and authorization decisions for “major infrastructure projects” as One Federal Decision (OFD). The OFD establishes a government-wide goal for the completion of EIS documents of no longer than 2 years, as measured from the date of publication of a notice of intent to prepare an EIS. The OFD also established agency concurrence points in the process.

In the FAA Reauthorization Act of 2018, several provisions were put in place to facilitate compliance with NEPA. Section 163 was designed to clarify and address FAA's responsibilities for non-aeronautical development. The Reauthorization limits the FAA's authority to "directly or indirectly regulate" such property transactions except to (1) ensure the safe and efficient operation of aircraft, or the safety of people and property on the ground; (2) to ensure the receipt of fair market value for the use or disposal of property; or (3) where the property was purchased with FAA grants or is subject to the Surplus Property Act. The Act also limits FAA's authority to review and approve Airport Layout Plan (ALP) amendments to only those amendments that "materially impact" safety and efficiency for aircraft operations, or that "adversely affect the value of prior Federal investments to a significant extent."[291] FAA has issued a Memorandum on Instructions to Airports District Offices and Regional Office of Airports Employees Regarding Airport Layout Plan Reviews and Projects Potentially Affected by Section 163 of the FAA Reauthorization Act of 2018.[292]

In 2019, the U.S. DOT issued "Interim Policy on Page Limits for NEPA Documents and Focused Analyses."[293] This memorandum applies to all U.S. DOT agencies and requires that EAs be no longer than 75 pages and EIS documents no longer than 150 pages. This page limit applies to "purpose and need for the action; alternatives, including the proposed action and no action; affected environment; and environmental consequences. In calculating the length of the document, the OA [operating administrations] should not include the executive summary, appendices, or materials incorporated by reference, if any." For "projects of unusual scope or complexity," EIS documents may be 300 pages and Mitigated Finding of No Significant Impact (FONSI) determinations no more than 150 pages.

On July 15, 2020, CEQ announced a final rule "Update to the Regulations Implementing the Procedural Provisions of the National Environmental Policy Act" modernizing their existing NEPA implementing regulations for federal agencies. The new rule codifies several streamlining practices federal agencies already use and introduced important changes to the NEPA process. Changes identified in the final rule include revised definitions for "effects" or "impacts," "major federal action," and "reasonable alternatives;" removal of analyses of cumulative impacts and impacts on climate change, and the "alternatives, information, and analysis" section of a final EIS; allows federal agencies to adopt another federal agency's categorical exclusion determination for similar actions; sets timelines and page limits for EA and EIS documents; limits analyses to "reasonably foreseeable… and close causal" effects; eliminates the requirement for a 30-day public comment period on draft EIS documents; and adds a requirement for federal agencies to track and disclose costs related to EIS development and review.[294]

CEQ's final rule requires federal agencies to develop new or revised NEPA-specific implementing procedures to align with the final rule within 1 year of the rule's effective date of September 14, 2020. NEPA projects currently in progress may continue using existing NEPA procedures and previous CEQ NEPA regulations and should indicate this information in their documents. CEQ's final rule is under review by Congress and the Government Accountability Office.[295]

FAA is currently updating its 2006 Order 5050.4B[296] and its associated Desk Reference[297] to address these recent rules, memorandums, and Orders.

Because of complaints about the duration of the NEPA process, the federal government has created the Federal Infrastructure Project Permitting Dashboard to provide agency and public visibility about the progress of projects.[298] As noted on its website, the Dashboard is designed to track "the Federal government's environmental review and authorization processes for large or complex infrastructure projects, part of a government-wide effort to improve coordination, transparency, and accountability." Originally designed to track EIS documents, agencies are now tracking both EIS documents and large EAs in the Dashboard. As of October 2020, the Dashboard includes 182 aviation projects (no FAST-41 projects and only one major infrastructure project) with a status listed as in progress or completed. Based upon progress shown in the Dashboard, the President releases its Infrastructure Permitting Accountability Scorecard, which enables a review of each agency's performance.

Despite these initiatives, a considerable gap in knowledge regarding aviation-related environmental review and compliance processes remains. There has been relatively little research 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 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 17: Approaches to Integrating Airport Development and Federal Environmental Review Processes* identified contributors to prolonged NEPA processes.[299] In mid-2013, ACI-NA issued a NEPA BMP guide identifying lessons learned over the last decade. The guide also recommended actions and issues that should be considered to better integrate project planning and environmental review processes.

ACRP Research Report 209: Integrating Airport Sustainability and the NEPA Process, provides airports with guidance on how to integrate sustainability into the analysis required under NEPA.[300] In 2020, the ACRP produced a tool and *ACRP Research Report 211: Guidance for Using the Interactive Tool for Understanding NEPA at General Aviation Airports*, to aid GA airports with identifying the NEPA requirements for various actions.[301]

Finally, while some projects have benefitted from these lessons learned, the past decade has seen limited major airport improvements projects due to national economic conditions that can help us understand the overall timeframes for planning and NEPA. Therefore, it is unclear if there are meaningful benefits from the lessons learned on past NEPA processing efforts. In the past few years, many airports are seeing tremendous growth, which will likely place renewed pressure on expeditious compliance with NEPA.

3.1.3 FUTURE VISION

Reducing the amount of time needed to comply with NEPA while maintaining stakeholder acceptance, meeting stated environmental goals, and ensuring legal compliance for FAA actions will require:

- Improved analytic tools
- Improved procedures that fully integrate environmental considerations into the earliest planning phases
- 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 environmental assessments

- Using sustainability and resiliency initiatives and measures to avoid or minimize 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 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
- 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 potential environmental impacts of projects and the alternatives considered
- Document in plain language and be clear, concise, and to the point so the public can readily understand the analysis. 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

Even with the various (and evolving) regulations and Orders, the intent of NEPA has not changed. A clear approach to the NEPA process will ensure a timely and concise environmental review for aviation projects to aid in decision-making for the projects and alternatives evaluated and allowing for public review.

NOTES

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Acronyms

Acronym	Definition
AATT	Advanced Air Transport Technology
AAVP	Advanced Air Vehicles Program
ACA	Airport Carbon Accreditation Program
ACARE	APMT
ACCRI	Aviation Climate Change Research Initiative
ACI	Airports Council International
ACI-NA	Airports Council International-North America
ACROS	Airport Climate Risk Operational Screening
ACRP	Airports Cooperative Research Program
ADF	aircraft deicing fluids
AEDT	Aviation Environmental Design Tool
AFFF	aqueous film-forming foam
AGL	above ground level
AIP	Airport Improvement Program
ALP	Airport Layout Plan
ANSI	American National Standards Institute
ANSP	Air Navigation Service Providers
AOSP	Airspace Operations and Safety Program
APMT	Aviation Portfolio Management Tool
APU	Auxiliary Power Unit
ARC-X	Adaptation Resource Center
ASCENT	Aviation Sustainability Center
ASTM	American Society for Testing and Materials International
ATB-EUI	Airport Terminal Building Energy Use Intensity
ATM	Air Traffic Management
AUVSI	Association for Unmanned Vehicle Systems International
AvGas	Aviation Gasoline
AWARE	Airport Weather Advanced Readiness
B	Billion
BCA	Benefit Cost Analysis
BMP	Best Management Practice

Acronym	Definition
BOD	Biological Oxygen Demand
BTT	blending to temperature
C	Celsius
CAA	Clean Air Act
CAAFI	Commercial Aviation Alternative Fuels Initiative®
CAEP	Committee for Aviation Environmental Protection
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
CGP	construction general permits
CH_4	methane
Climate-ADAPT	European Climate Adaptation Platform
CLEEN	Continuous Lower Energy Emissions and Noise
CMAQ	Community Multiscale Air Quality
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide equivalent
COD	Chemical Oxygen Demand
COMSTAC	Commercial Space Transportation Advisory Committee
COP	Conferences of Parties
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CSS	Common Support Services
CWA	Clean Water Act
dB	decibel
DFW	Dallas-Fort Worth International Airport
DNL	Day-Night Noise Level
DOT	Department of Transportation
EASA	European Aviation Safety Agency
eGSE	Electric Ground Support Equipment
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
ERA	Environmentally Responsible Aviation
EUI	Energy Use Intensity
EUROCONTROL	European Organisation for the Safety of Air Navigation

Acronym	**Definition**
F	Fahrenheit
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FICAN	Federal Inter Agency Committee on Aviation Noise
FOG	Fats, Oils, and Grease
FONSI	Finding of No Significant Impact
FSC	fuel sulfur content
FTA	Federal Transit Authority
GA	General Aviation
GARDN	Green Aviation Research and Development Network
GAV	Ground Access Vehicle
GCM	general circulation models
GHG	Greenhouse Gas
GPS	Global Positioning System
GPU	Ground Power Unit
GSE	Ground Support Equipment
GSI	green stormwater infrastructure
Gt	Gross tons
HAI	Helicopter Association International
HAP	Hazardous Air Pollutants
HEFA	Hydroprocessed Esters and Fatty Acids
HinT	Health in Transportation
HVAC	Heating, Ventilation, and Air Conditioning
IASP	Integrated Aviation Systems Program
ICAO	International Civil Aviation Organization
IPCC	Intergovernmental Panel on Climate Change
Kg	Kilograms
LAX	Los Angeles International Airport
LEAP	Leading Edge Aviation Propulsion
LID	Low-Impact Development
LIDAR	Light Detection and Ranging
LTO	Landing Take Off
MESTANG	More Electric Systems and Technologies for Aircraft in the Next Generation

Acronym	Definition
M	Million
mph	miles per hour
MSGP	Multi-Sector General Permit
NAAQS	National Ambient Air Quality Standards
NAC	Noise Advisory Circular
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NCDEQ	North Carolina Department of Environmental Quality
NCI	Noise Compliance Initiative
NCSU	North Carolina State University
NEPA	National Environmental Policy Act
NextGen	Next Generation Air Transportation System
NLR	Noise Level Reduction
NOAA	National Oceanic and Atmospheric Administration
NO_X	Nitrous oxides
NPDES	National Pollutant Discharge Elimination System
O_3	Ozone
OAT	Outside Air Temperature
OFD	One Federal Decision
OST	Office of the Secretary of Transportation
PANYNJ	Port Authority of New York and New Jersey
Pb	Lead
PBN	Performance Based Navigation
PCA	Pre-conditioned air
PFAS	per- and polyfluoroalkyl substances
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctanesulfonic acid
$PM_{2.5}$	Particulate matter less than 2.5 microns
PM_{10}	Particulate matter less than 10 microns
RNAV	Area Navigation
SAF	Sustainable Aviation Fuels
SAGA	Sustainable Aviation Guidance Alliance
SAN	San Diego International Airport

Acronym	**Definition**
SCM	Stormwater Control Measures
SDCRAA	San Diego County Regional Airport Authority
SESAR JU	Single European Sky ATM Research Joint Undertaking
SIP	State Implementation Plan
SMP	Sustainable Master Plan
SOx	Sulfur oxides
SO_2	Sulfur dioxide
sUAS	Small Uncrewed Aircraft Systems
TAPS	Twin Annular Premixing Swirler
TBO	Trajectory Based Operations
TRB	Transportation Research Board
TSS	Total Suspended Solids
UAM	Urban Air Mobility
UAS	Uncrewed Aircraft Systems
UFP	Ultrafine Particulate Matter
U.K.	United Kingdom
UNFCCC	United Nations Framework Convention on Climate Change
U.S.	United States
USACE	U.S. Army Corps of Engineers
VALE	Voluntary Airport Low Emissions
VFS	Vertical Flight Society
VLOS	Visual Line of Sight
VOC	Volatile Organic Compounds
VPRP	Voluntary Pollution Reduction Program
VTOL	Vertical Takeoff Landing
WOTUS	Waters of the U.S.
WQS	Water Quality Standards
WSDOT	Washington State Department of Transportation
WSPR	Waveforms and Sonic boom Perception and Response

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