Commercial Aviation: A New Era

For the U.S. Economy and Global Prestige

Workshop Overview

A workshop organized by

The INCE Foundation in Cooperation with NASA and the FAA

hosted by

The National Academy of Engineering, Washington, DC

Tamar Nordenberg, rapporteur

edited by

Adnan Akay, Gregg G. Fleming, Robert D. Hellweg, George C. Maling, Jr., and Eric W. Wood

Institute of Noise Control Engineering of the USA

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PREFACE

This document is an overview of a workshop hosted by the National Academy of Engineering (NAE) in Washington, DC on May 8–9, 2017. The workshop, *Commercial Aviation: A New Era*, was organized by the INCE Foundation in cooperation with the National Aeronautics and Space Administration (NASA) and the Federal Aviation Administration (FAA). The organizing committee consisted of Adnan Akay, Provost of Bilkent University, Gregg G. Fleming, Volpe Transportation Systems Center, Robert D. Hellweg, Hellweg Acoustics, George C. Maling, Jr., Member, NAE, and Eric W. Wood, Acentech Incorporated.

The workshop program is shown in Appendix A, and the list of attendees is shown in Appendix B. This overview will be followed by a full report of the workshop that includes a summary of each presentation and images of selected slides shown at the meeting. The report coverage will be broader than the relevant chapter of the *Technology for a Quieter America* (TQA)[†] NAE report published by the National Academes Press in 2010. That report covered NASA technology goals for America as well as European noise technology. It also contained recommendations for action by NASA and the FAA:

> **Recommendation 5-1:** The National Aeronautics and Space Administration (NASA) should continue to fund collaborative projects by engine, airframe, and aircraft systems manufacturers. Drawing on expert knowledge in research organizations and academic institutions, research should focus on the complex interrelationships between engine and airframe and the importance of reducing each constituent noise source to reduce the overall noise signature of aircraft. These projects should develop improved prediction tools, for example, for advanced propulsion designs; acoustic scattering and propagation models, including adequate weather and terrain models; models of the effects of interactions between engine installation and airframe configuration; and benchmark measurements necessary for the development and validation of these advanced tools.
>
> **Recommendation 5-2:** The Federal Aviation Administration should continue to fund the development of novel operational and air traffic management procedures to minimize noise and should work with NASA and industry to make intelligent trade-offs between competing noise mitigation and chemical pollution goals.

This workshop was held under an NAE policy announced to the membership on Oct. 20, 2016 [‡] that describes workshops initiated by members and approved by the NAE. Earlier, the NAE approved workshops on an ad hoc basis, and they were held as NAE-hosted workshops by a TQA follow-on team. Reports from these NAE-hosted workshops can be found at http://www.inceusa.org/publications/technical-reports.

[†] http://www.nap.edu/catalog.php?record_id=12928

[‡] The NAE supports and encourages members and sections to develop ideas for new consensus studies and non-consensus convening activities (seminars. workshops. roundtables. symposia. meetings. etc.) that serve to advance the NAE mission and objectives, whether led and organized by the NAE or other units of the National Academies of Sciences, Engineering, and Medicine (National Academies) or by NAE sections or groups of NAE members. The NAE's 2015 Strategic Plan specifically calls out increased member engagement as an objective. Member- and section-inspired activities also serve to build camaraderie and a greater sense of purpose among members and within and between sections. Therefore with the support of the NAE Council we are piloting a new process to more effectively engage our membership in the development and execution of consensus studies and non-consensus convening activities. (*The balance of the announcement concerns process—Ed.*).

Workshop Overview

Over the past 60 years, the U.S. has established itself as the global leader in the aviation industry. Boeing, still the largest producer of commercial aircraft worldwide, captured 43.4 percent of global commercial aircraft sales in 2015 and invested $3.3 billion in research and development in that year. General Electric and Pratt & Whitney continue to be the leaders in aircraft engine propulsion.

Commercial aviation manufacturing is the top U.S. net export, generating a positive trade balance of $59.9 billion in 2014. The aviation sector as a whole is a critical linchpin of the U.S. economy, generating an estimated half-million high-paying U.S. jobs, according to the Bureau of Labor Statistics. Overall, commercial aviation is integral to U.S. economic stability, generating an estimated $1.6 trillion in economic activity and accounting for 5.1 percent of total gross domestic product in the U.S. in 2014.

Where noise from commercial aviation is concerned, considerable progress has been made in reducing noise, yet it continues to pose a major challenge for the aviation industry and, if not adequately addressed, could substantially inhibit future growth. Research over the past several decades (conducted mostly outside the U.S., often in Europe and Japan) has suggested that the noise generated from aircraft is associated with a number of harmful impacts on human health and community well-being. The May 2017 workshop saw general agreement among noise effect researchers that aircraft noise causes community annoyance. It might also affect children's cognitive performance, disturb sleep, and might be associated with an increased risk of cardiovascular disease, making noise reduction an important goal.

If the U.S. wants to maintain its status as a global leader in the commercial aviation industry, it is imperative that the country invest more heavily in aviation-related environmental research and development. Otherwise, the U.S. risks losing its international leadership status to Europe or China, where recent R&D investments have dwarfed those in the U.S.

Aviation is a target industry for technology investment and development in the U.S. and in other countries, with significant resources invested toward improving fuel efficiency and reducing noise. These two parameters are interrelated, with many technological advancements providing reductions in both noise and fuel use. For example, the introduction of the high-bypass ratio turbofan in the 1970s was aimed at reducing fuel burn but also led to significant reductions in noise. Figure 1 shows aircraft noise reductions associated with technological changes since 1960. The interdependency between noise and fuel burn in some engine developments, including the high-bypass ratio turbofan and the geared turbofan, demonstrates that source noise reduction goals can be met while also helping to reduce airline operating costs associated with fuel consumption.

The reduction in noise generated by aircraft has meant that substantially fewer people are subject to high noise levels. Since 1975, for example, there has been a 95 percent reduction in population exposed to day-night average sound level (DNL) of 65 dB, a threshold established by the FAA and others for acceptable levels of exposure to aircraft noise. DNL, which measures the average weighted noise level over a 24-hour period with a penalty for nighttime operations, is correlated with population annoyance. Reduction in the number of people exposed to DNL 65 and greater has occurred even as the number of passengers traveling on commercial airlines in the U.S. increased by 260 percent over the same period (Figure 2).

Despite considerable reductions, noise remains a constraint on aviation growth due primarily to community response to aircraft noise. While investment in technology is absolutely critical, it will take years for new designs to substantially penetrate the operating fleet, despite the large number of older aircraft that are being retired from the fleet. Therefore, other strategies for

reducing aircraft noise in the near term must be undertaken. These strategies generally follow the balanced approach established by the International Civil Aviation Organization (ICAO), which uses a variety of noise abatement techniques including land-use planning, operational procedures, restrictions, and community engagement, in addition to source noise reduction. For example, since 1982 the U.S. government has provided over $10.5 billion in funding to support sound insulation of homes and schools around U.S. airports. In the future, at least a portion of this type of funding may be better placed in aircraft/engine source noise reduction efforts.

The increased reliance on precision-based navigation (PBN), which allows for more precise airline route planning, is an example of an operational strategy that has been effective at reducing overall noise exposure in the vicinity of airports. PBN, however, has also led to substantial noise increases at specific locations directly beneath the flight tracks. PBN is most effective when noise-compatible land such as waterways or industrial corridors are available near airports, facilitating flight tracks that avoid residential communities. Since few airports have the land resources to optimize the use of this technology as a noise reduction strategy, communities have had to deal with the unintended noise consequences. Figure 3 shows flight tracks at a major U.S. airport before (green) and after (red) the introduction of PBN. As the figure shows, there is an increased concentration of flights along narrow corridors. Although current PBN routes result in fewer individuals being affected by noise from airplane overflights, those individuals located directly underneath the flight tracks are subject to increases in noise. Community engagement surrounding aircraft noise issues has also resulted in increased complaints, increased political engagement, and a substantial uptick in related lawsuits—suggesting that the noise effects of PBN require special consideration.

While short-term efforts focused on operational strategies are important and have been effective at reducing exposure to noise pollution, they will not be sufficient on their own to support continued growth of the U.S. commercial aviation industry. Therefore, investments in long-term solutions targeted at reducing aviation noise at the source are critical.

There was consensus among experts at the May 2017 workshop that a paradigm shift from the traditional tube and wing design is needed to achieve continued substantial noise reductions. As the U.S. looks toward future technological improvements, understanding the interdependencies between noise, emissions, and fuel burn is particularly important. While noise is the significant environmental issue for communities, fuel burn is critical to the airlines as fuel represents roughly one-third of airline operating costs. The industry has recently introduced significant engine technology advances, including the development of the geared turbofan, that have led to improvements in both noise and fuel burn. In addition, the industry continues to look at state-of-the-art advancements such as the open rotor design aimed at producing substantial improvements in fuel burn with no major noise penalties. Substantial and sustained technological investment is needed to achieve the reductions that many experts consider possible, as seen in the latest NASA technology goals (Figure 4).

Stakeholder collaboration is key to continued success in achieving technological improvements in aircraft (Figure 5). Airlines and commercial aviation manufacturers have expressed a need to move forward in the development of quieter, more efficient aircraft, but they are ill-equipped to make these investments and take on the associated risk on their own.

Universities will play an important role in these efforts by advancing research that informs industry experts and by providing a pipeline of people with the skills to develop and implement the new products. Investments in Science, Technology, Engineering, and Math (STEM) programs across all academic levels will be crucial to ensuring a labor force qualified to support continued research and innovation in aircraft noise reduction. In addition, U.S. government support will be critical, especially in early stages of development, to reduce risk and encourage

industry investment. Without buy-in from stakeholders across the board, the U.S. will be unable to achieve the desired innovations and maintain its leadership position in the aviation industry.

Through NASA and FAA efforts, the U.S. government is successfully utilizing public-private partnerships (P3) with the U.S. aviation industry to advance aircraft technology. Between 2010 and 2020, the FAA will have invested roughly $225 million in the Continuous Lower Energy, Emissions and Noise (CLEEN) program. With a 50-50 industry-government cost-share structure, combined investment in this project will total $450 million over a 10-year period (roughly $45 million per year). Only a fraction of NASA investments follow a similar P3 model. Over the past 10 years, NASA aeronautics has funded roughly $1.6 billion in vehicle-related research for improved efficiency and environmental performance. In contrast, the European Clean Sky 2 Initiative—which is structured under a similar 50-50 industry-government cost-share model—plans to invest roughly $4 billion in commercial aviation technological improvements over a 7-year period that began in 2014 ($570 million per year). The European initiative includes a goal of producing a step-change reduction in aircraft noise emissions, and recognizes that incremental changes will not be sufficient to fully meet the industry's needs. The Chinese government has also made aviation investment a priority, and has recently approved an aircraft engine development program. China's President Xi Jinping called the creation of the new company a "strategic move" aimed at developing China's reputation as a global aviation power. Industry experts forecast that the Chinese government will invest upwards of $49 billion over the next two decades to support this effort.

The P3 model is essential to industry because it reduces the technical, financial, and market risks associated with approaching new ventures. Without substantial U.S. government assistance, companies are unlikely to invest in the types of research that could produce the desired noise-reduction outcomes. There is a strong need for a step-change in environmental performance, which will require radically different designs such as the double-bubble and blended wing configurations (Figure 6). These modifications have the potential to significantly improve aerodynamic performance, which could provide marked improvements in fuel efficiency while providing engine noise shielding, which would provide noise reduction relative to existing aircraft technology.

As stated previously, a step-change in noise reduction will need to be accompanied by a step-change in fuel burn while ensuring continued safe operation. The path toward such a significant step-change in design must include the development and testing of flight demonstrators to evaluate new concepts. This is expensive. Workshop experts from the U.S. government, industry, and academia agreed that current levels of U.S. investment in aircraft technology are insufficient, noting that without sharp budget increases the continued leadership role of the U.S. in aviation is in jeopardy. NASA's 10-Year American Aviation Plan cited during the workshop outlines a framework for implementing the type of forward-thinking efforts summed up in Figure 4. The NASA document suggests that this progress would require increases in funding for the Aeronautics Research Mission Directorate and necessitate roughly a doubling of the program's annual budget from $640 million in 2016 to $1.3 billion by 2023.

The U.S. is poised to lead innovation and reap the rewards of the next generation of aircraft advances, including associated high-paying jobs and other economic benefits. If the U.S. is willing to make substantial investments and prioritize sustained collaboration between government, industry, and academia, the country will position itself to serve as the global leader in the commercial aviation industry for decades to come.

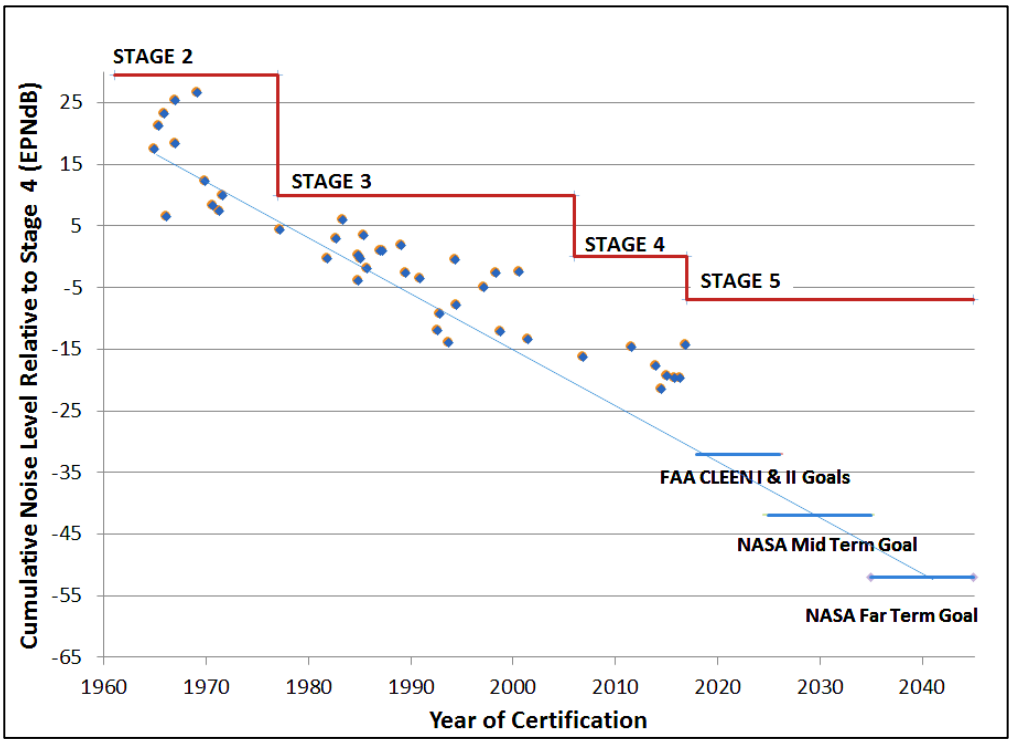

Figure 1. *Certified Aircraft Noise Levels, Including Projections (1960–2040)*

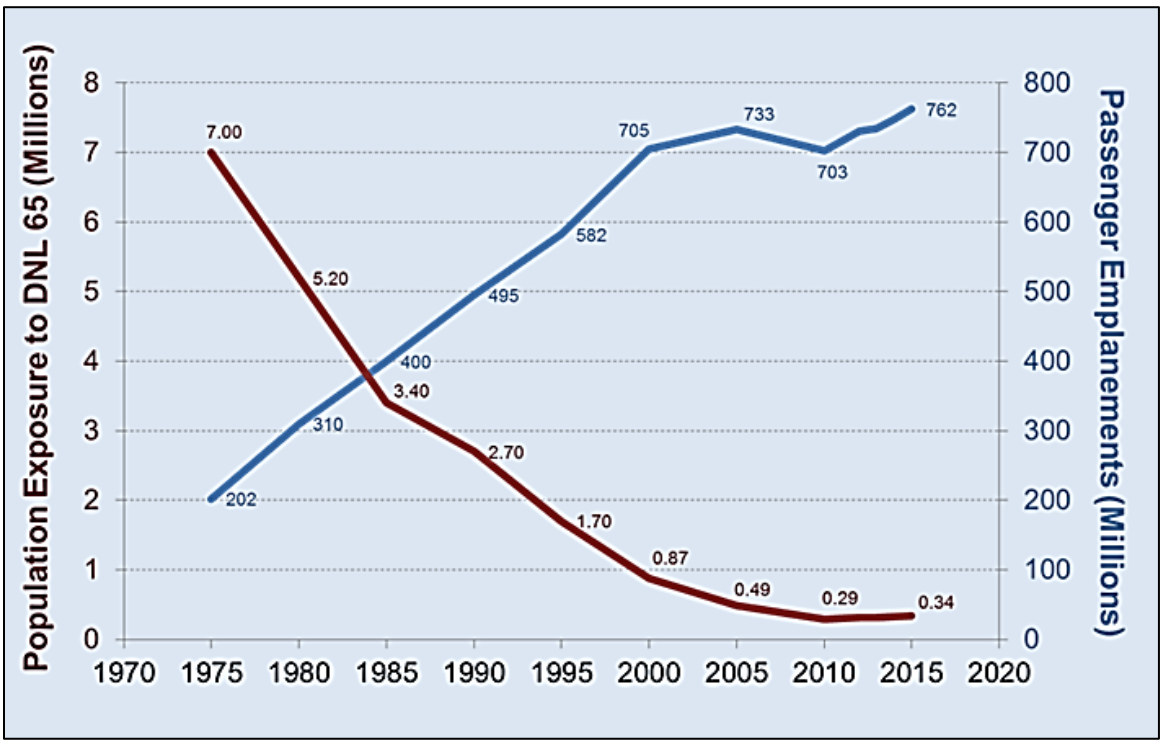

Figure 2: *Number of Enplanements Versus Number of People Exposed to DNL 65 dB or Higher (1970–2015)*

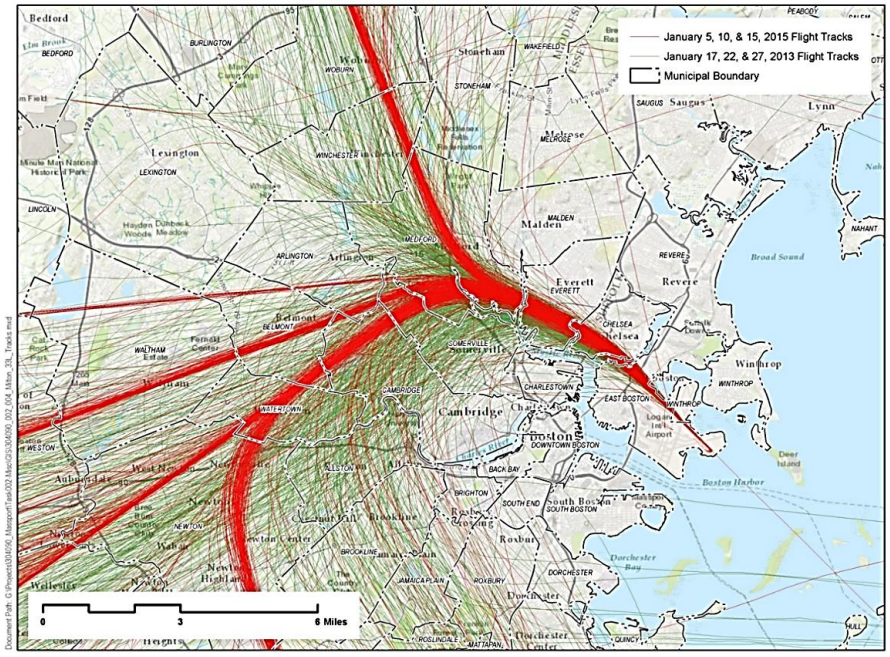

Figure 3. *Flight Tracks at a Major U.S. Airport Before (Green) and After (Red) Implementation of PBN*

TECHNOLOGY BENEFITS	TECHNOLOGY GENERATIONS (Technology Readiness Level = 5-6)		
	Near Term 2015-2025	Mid Term 2025-2035	Far Term beyond 2035
Noise (cum 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 (Reduction rel. to 2005 best in class)	65 – 70%	80%	>80%
Aircraft Fuel/Energy Consumption (Reduction rel. to 2005 best in class)	40 – 50%	50 – 60%	60 – 80%
	Evolutionary	Revolutionary	Transformational

Figure 4. *NASA Near-, Mid-, and Far-Term Environmental Technology Goals*

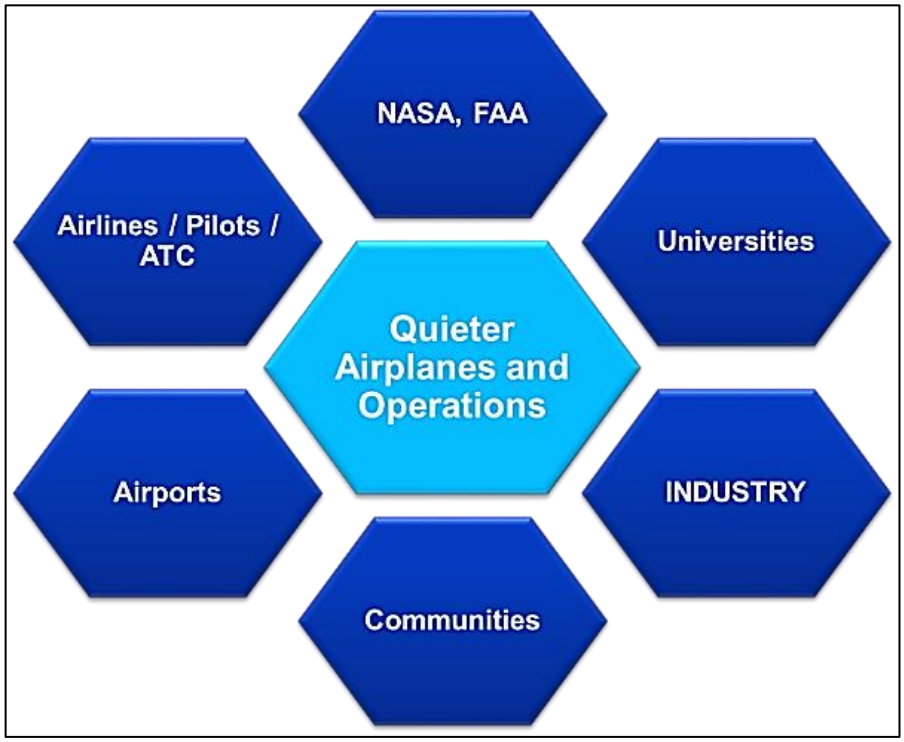

Figure 5. *Stakeholders in Commercial Aviation Innovation*

Figure 6. *Examples of Conceptual Aircraft Designs*

Appendix A

Final Workshop Agenda

Engineering a Quieter America
Commercial Aviation: A New Era

A Workshop Organized by the INCE Foundation
in Cooperation with NASA and the FAA

Hosted by the National Academy of Engineering

May 8–9, 2017
The National Academies Keck Center
Room 100, 500 5th Street, NW
Washington, DC 20001

DAY 1 PROGRAM

8:30–9:30	**Welcome** **Opening Remarks** Alton D. Romig, Jr. Executive Officer, National Academy of Engineering **Current Status and Goals of the Workshop** Jay Dryer, Director, Advanced Air Vehicles Program Aeronautics Research Mission Directorate, NASA James Hileman, Chief Scientific and Technical Advisor for Environment and Energy, FAA **Introduction of Participants** (Name and affiliation only)
9:30–10:05	**A Brief History of Aviation (up to 1970s), Technology Development Since the Beginning of the Jet Age—1958** Eric Wood, Acentech Incorporated, Workshop Steering Committee
10:05–10:35	**BREAK**
10:35–10:55	**Effects of Aviation Noise on Humans: Learning, Sleep, Quality of Life** Mathias Basner, University of Pennsylvania

10:55–11:35 **NextGen: Noise and the New Navigation System**
John Hansman, Massachusetts Institute of Technology
(Remote)

11:35–12:35 **Economic Impact of Air Transportation**
Liying Gu, Airports Council International
Thea Graham, Manager, Economic Analysis, FAA

12:35–1:35 **Lunch in the NAE Cafeteria**

1:35–3:35 **Current Noise Constraints on Aviation and the Future with Low- Noise Technology**
Sandy Lancaster, Dallas Fort Worth Airport
Flavio Leo, Massport
Glenn Morse, United Airlines
Steve Alterman, Cargo Airline Association

Discussion will cover:
Operating hours, land use planning, airport operator constraints. Cost of constraints: Residential sound insulation program, other costs such as land-use planning. Cost of noise reductions and the cost of opportunities lost.
What will be the benefits to the nation's air transportation system when low-noise airplanes are developed and the constraints discussed above lifted?

3:35–4:05 **BREAK**

4:05–5:05 **Opportunities With a Low Noise Future (panel discussion)**
Megan Knight, N.O.I.S.E., Panel Moderator

Attendees from airports, airlines, and communities will discuss opportunities afforded by technology advancement to reduce aircraft noise. What technology changes would entice them to invest in the future (buy, develop, plan, etc.)

DAY 2 PROGRAM

8:30–9:00 **Keynote Speech: Maintaining America's Leadership in Aviation**
Carl Burleson
Deputy Assistant Administrator, Policy, International Affairs, and Environment
FAA

9:00–9:30 **FAA Perspective on the Challenges Posed by Aircraft Noise**
James Hileman, FAA

The emphasis will be on the challenges posed by aircraft noise and how these could be overcome through improved knowledge, new technology, and mitigation measures.

9:30–10:00 **The Future of Aviation: The NASA Strategic Plan**
Jay Dryer, NASA

The NASA emphasis will be on N+1 and N+2 performance levels, with a focus on near-term (to 2025) and mid-term (2025-2035) performance. Discussion will cover new concepts, enabling technologies, and innovative approaches to noise reduction.

10:00–10:30 **BREAK**

10:30–11:00 **X-Plane history, the X48C, and Beyond**
Ed Waggoner, NASA

A brief review will be presented of X-plane development, up to the X-48C, and the development of a new X-plane by NASA will be discussed. Emphasis will be on airplanes, engines, and low-noise design, taking into account environmental concerns such as emissions, fuel burn, and noise.

11:00–11:30 **Engine Development: The Prospects for Future Engines—Quieter, Cleaner, and Environmentally Protective**
Michael Winter, Pratt & Whitney
John Kinney, General Electric

What will the airplane engine of the future look like?

11:30–12:00	**Airplane Design: Possibilities for the Future** Brian Yutko, Aurora Aviation Mark Page, DZYNE Technologies *This presentation will focus on innovative airplane designs, including blended wing and engines mounted on the fuselage above the wing. What can be learned from the development of military airplanes and what can be adopted for commercial use?*
12:00–1:00	**Lunch in the NAE Cafeteria**
1:00–1:30	**A Roadmap for European Aeronautics to 2050** Giuseppe Pagnano, Clean Sky Joint Undertaking *Areas of focus will be the Advisory Council for Aviation Research in Europe (ACARE), the Strategic Research and Innovation Agenda (SRIA), FlightPath2050 goals, and the Clean Sky initiative.*
1:30–2:30	**An Overview of the United States Aircraft Industry** Jeanne C. Yu, Boeing Commercial Airplane Company
2:30–3:00	**BREAK**
3:00–4:00	**Achieving a Low-Noise Future** (**panel discussion)** Steve Alterman, Panel Moderator *Cooperation among government, industry, and academic sectors will be needed to produce a low-noise air transportation system. The way to move forward, including academic research, will be explored. The role of government, industry, and private-public partnerships will be discussed.*
4:00–4:45	**Summary of the Workshop** (by workshop organizers)
4:45–5:00	**Closing Remarks** George Maling and Adnan Akay, Workshop Steering Committee

Appendix B

Workshop Attendees

Commercial Aviation: A New Era

May 8–9, 2017

Akay, Adnan
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Bilkent University

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President
Cargo Airline Association

Angleman, Alan
Senior Program Officer
Aeronautics and Space
Engineering Board
National Academies of Sciences,
Engineering, and Medicine

Basner, Mathias
Associate Professor
Psychiatry
University of Pennsylvania

Burleson, Carl
Deputy Assistant Administrator,
Policy, International Affairs,
and Environment
FAA

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Senior Director, Safety, Airport Programs
and Environmental Affairs
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Airbus Americas, Inc.

Cointin, Rebecca
Manager
Noise Division
FAA

Dryer, Jay
Program Director
ARMD
NASA

Eagan, Mary Ellen
President
HMMH

Fleming, Gregg
Director
Policy, Planning, and Environment
U.S. DOT

Geneus, Chantal M.
Atkinson Baker

Graham, Thea
Manager
Air Traffic Organization
FAA

Gu, Liying
Managing Director, Finance and Research
Airports Council International-NA

Hansman, John (Remote)
T. Wilson Professor of Aeronautics & Astronautics
MIT

Hellauer, Kurt M.
Director, Federal Programs
HMMH

Hellweg, Robert D.
Principal
Hellweg Acoustics

Hileman, Jim
Chief Scientist and Technical Advisor
Office of Environment and Energy (AEE-3)
FAA

Holzer, Michael
Senior Program Assistant
Program Office
National Academy of Engineering

Levent, Ileri
CLEEN Program Manager
FAA

Kassaraba, Myron J.
Representative
Logan Airport Community Advisory Committee
Town of Belmont

Kinney, John F.
Director, Advanced Technology Business Development
Advanced Technology Operations
GE Aviation

Knight, Megan G.
N.O.I.S.E.
Lockridge Grindal Nauen P.L.L.P

Lang, Robert
Engineer
IBM

Lancaster, Sandy
Environmental Program Manager
Environmental Affairs
Dallas Fort Worth Airport

Leo, Flavio
Director, Aviation Planning and Strategy
Strategic and Business Planning
Massachusetts Port Authority

Maling, Jr, George C.
Member, NAE

Marks, Julie
ATO Community Manager
Air Traffic Organization
FAA

Marshall, Steven E.
President
Scantek, Inc.

Morse, Glenn F.
Director-Industry Affairs
Network Operations Control
United Airlines

Mote, Jr., C.D.
President
National Academy of Engineering

Nordenberg, Tamar
Rapporteur
Vie Communications

O'Connor, Jennifer
Atkinson Baker

Page, Mark A.
VP-Chief Scientist
DZYNE Technologies

Pagnano, Giuseppe
Coordinating Project Officer/CTO
Clean Sky Joint Undertaking

Potter, Jim
Community Planner
Office of Environment and Energy
HUD

Reid, Proctor
Director
Program Office
National Academy of Engineering

Romig, Jr., Alton D.
Executive Officer
National Academy of Engineering

Ronzello, Gina C.
Director Government Affairs
Cargo Airline Association

Tang, Stanley
Program Management Support Officer
Clean Sky 2 Joint Undertaking

Waggoner, Ed
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Integrated Aviation Systems Program
NASA

Wahls, Richard A.
Strategic Technical Advisor
Advanced Air Vehicles Program
NASA

Winter, Michael
Senior Fellow, Advanced Technology
Pratt & Whitney, UTC

Wood, Eric W.
Consultant
Acentech Incorporated

Young, Nancy N.
Vice President of Environmental Affairs
Airlines of America

Yu, Jeanne C.
Director, Technology Integration
Product Development
Boeing Commercial Airplanes
The Boeing Company

Yutko, Brian
D8 X-Plane Program Manager
Aurora Flight Sciences Corp.
and MIT

Maintaining America's Global Leadership in Aviation Technologies

Boeing, Lockheed Martin, Pratt & Whitney, General Electric