Engineering a Quieter America

Commercial Aviation: A New Era

Workshop Final Report

A workshop organized by

The INCE Foundation in Cooperation with NASA and 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

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This report has been approved by the Board of Directors of INCE-USA for publication as a public information document. The content, opinions, findings, conclusions, and recommendations expressed in the report do not purport to present the views of INCE-USA, its members, or its staff.

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[1] Deceased, October 23, 2016

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PREFACE

This document is the final report on a workshop hosted by the National Academy of Engineering (NAE) in Washington, DC on May 8–9, 2017. It includes a summary of each presentation and images of selected slides shown at the meeting. 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. The report coverage is 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 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.*).

ACKNOWLEDGMENTS

This TQA follow-up initiative exemplifies the NAE's commitment to the social value of engineering. The report has been reviewed in draft form by members of the *Technology for a Quieter America* (TQA) Advisory Board, all of whom are noted for their technical expertise in noise control engineering and acoustics, and many of whom contributed to the preparation of the TQA report published by the National Academies Press in October 2010. The Advisory Board members' contributions to this report represent their enduring dedication to a quieter America.

The NAE's support in hosting the workshop is very much appreciated. Special thanks to Proctor Reid, director of the project office, and NAE senior program assistant Michael Holzer.

This report could not have been written without the assistance of rapporteur Tamar Nordenberg. She wrote the workshop presentation summaries, which were then reviewed by the presenters. With technical assistance from the editors, she produced a cohesive, readable report.

The editors, George Maling, Gregg Fleming, Eric Wood, Adnan Akay, and Robert Hellweg, put in many hours in the preparation of this report, and are grateful to the authors of all of the papers for their presentations at the workshop and for reviewing the associated summaries.

The support of the INCE Foundation and the Noise Control Foundation is gratefully acknowledged.

Finally, thanks to the NAE's Committee on *Technology for a Quieter America*, chaired by George Maling, which produced the 2010 NAE TQA report with its numerous findings and recommendations.

CONTENTS

OVERVIEW

This report contains summaries of the papers presented at a workshop hosted by the National Academy of Engineering (NAE) on May 8–9, 2017.

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 OV-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 Pratt & Whitney's PurePower® Geared Turbofan™ engine, 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 OV-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 performance-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 OV-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 OV-4).

Stakeholder collaboration is key to continued success in achieving technological improvements in aircraft (Figure OV-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 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. Two industry experts at the workshop stated that the Chinese government plans aviation investments of $300 billion over the next two decades.

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 OV-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 OV-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.

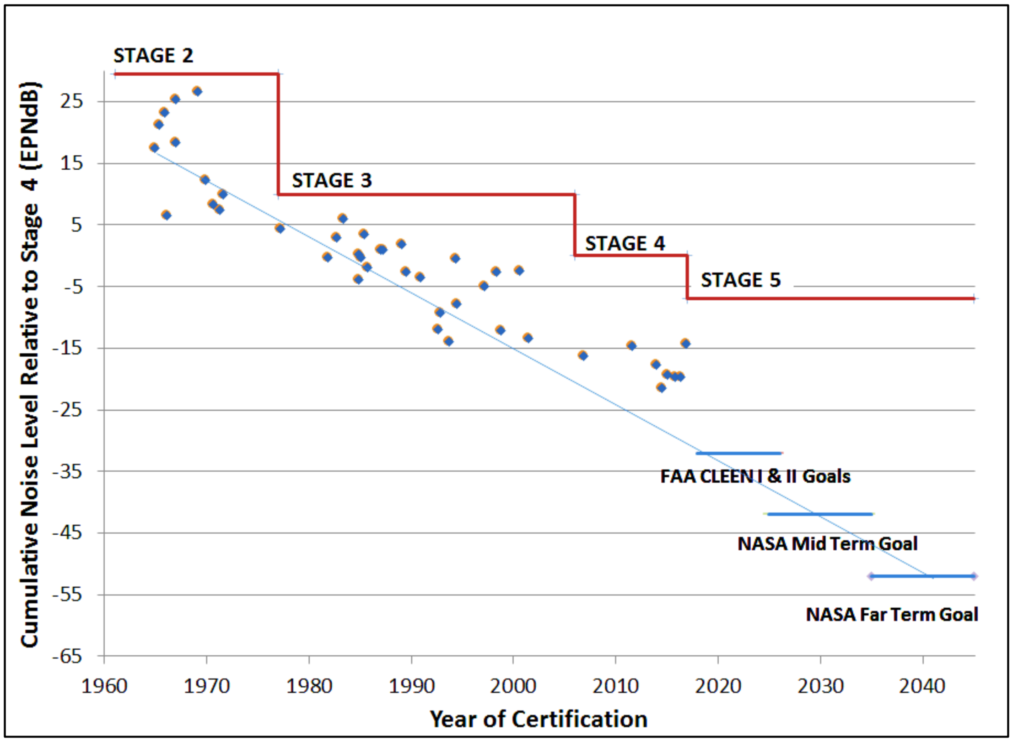


Figure OV-1. *Certified Aircraft Noise Levels, Including Projections (1960–2040)*

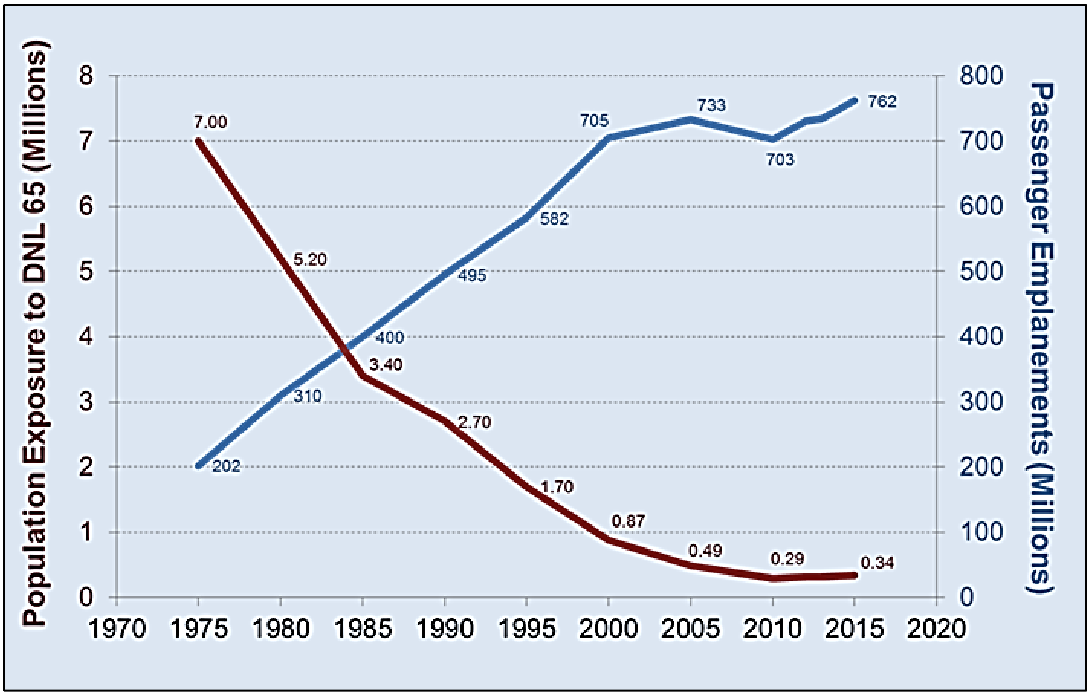


__Figure OV-2:__ Number of Enplanements Versus Number of People Exposed to DNL 65 dB or Higher (1970–2015)

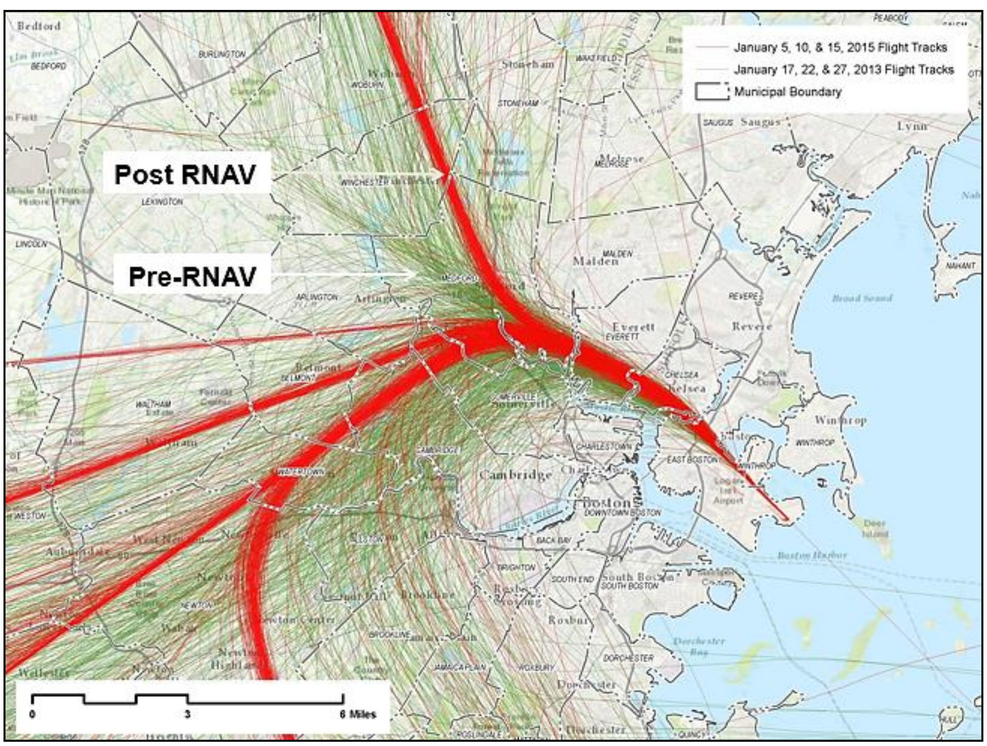


__Figure OV-3.__ Flight Tracks at a Major U.S. Airport Before (Green) and After (Red) Implementation of PBN

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%

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

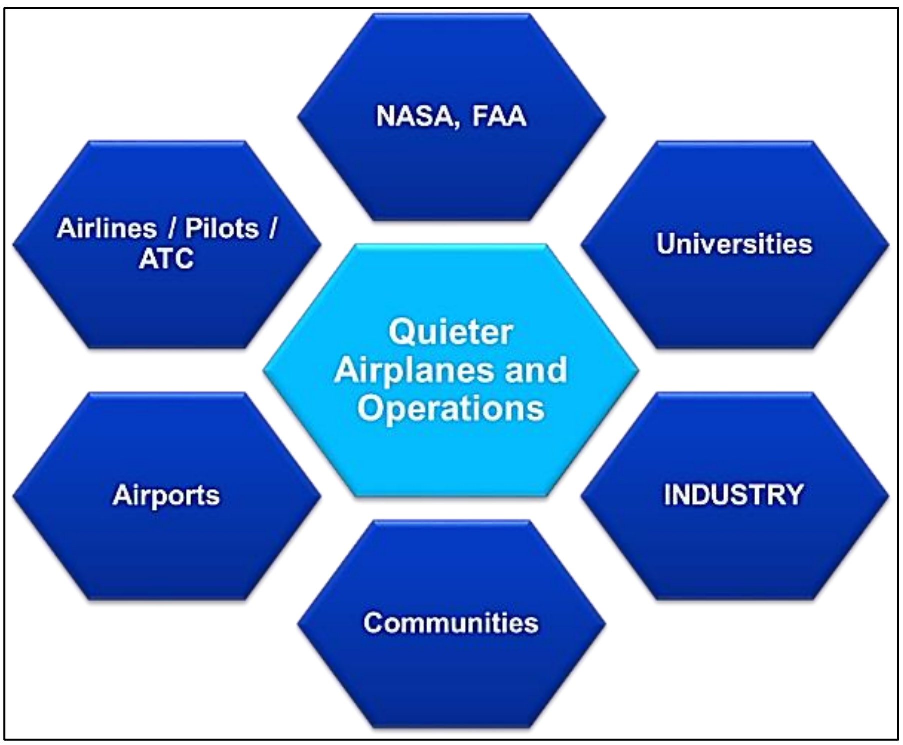


Figure OV-5. *Stakeholders in Commercial Aviation Innovation*

Figure OV-6. *Examples of Conceptual Aircraft Designs*

1

INTRODUCTION

Background

The report *Technology for a Quieter America*[1] (TQA), published in 2010 by the National Academies Press on behalf of the National Academy of Engineering (NAE), emphasizes the importance of engineering—and, in particular, the role of noise control technology that supports a quieter environment— to the quality of life in America. Implementation of the recommendations in the report will result in reduction of the noise levels to which Americans are exposed and will improve the ability of American industry to compete in world markets where increasing attention is being paid to the noise emissions of products—including aircraft.

Workshops conducted by a follow-up team, organized by the INCE Foundation and hosted by the NAE, have been held on a variety of engineering and economic subjects related to the TQA Report. Previous NAE-hosted workshop reports have been published as public information documents by INCE-USA, and can be found and downloaded without cost from the organization's website, INCEUSA.org, by choosing "INCE-USA Reports" under "Publications." Among these reports is a concise overview report of this aviation workshop that was published and distributed in September 2017.

Scope and Purpose of the Workshop

This workshop on the future of commercial aviation was held on 8 and 9 May of 2017. The overall theme of the workshop centered around the importance of commercial aviation to the U.S. economy and what it will take for the U.S. to maintain global leadership in the aviation sector. One specific, forward-looking topic of the workshop was more environmentally friendly aircraft designs.

A principal focus of the workshop and this report is the necessary step-changes in aircraft engineering technology that must now be addressed with the development and testing of flight demonstrators together with significantly increased funding of public-private partnerships. These changes are necessary for the U.S. aviation industry to maintain its global leadership and positive trade balance. Aviation technology investments in Europe and China are now significantly exceeding those in the U.S.

Content

Today's commercial aircraft have a global reach and provide unprecedented transportation safety, better fuel efficiency, lower emissions, and less noise compared to those of the past. A wide range of advances —accomplished, ongoing, and planned—were discussed during the workshop. For example, attendees discussed the studies being conducted by NASA and FAA, in

[1] https://www.nap.edu/catalog/12928/technology-for-a-quieter-america

partnership with the aviation community, universities, and consulting firms, to support improvements in the design, efficiency, noise, and economics of future aircraft. The significant importance of X-plane or X-system development and flight testing for the successful future of U.S. aviation was also emphasized.

This report includes a summary of each workshop presentation and two roundtable discussions (listed in the Table of Contents and Appendix A). Included as appendices are the workshop agenda, a list of workshop attendees, a list of acronyms and definitions, and two NASA-produced auralizations of current and future aircraft overflights.

Subjects addressed during workshop presentations include current noise constraints on aviation, how to achieve a future without constraints, economics of air transportation, X-plane history and the future of aviation, engine developments and future airplane designs, overview of the U.S. aviation industry, effects of aviation noise on humans, and a brief history of aviation.

A professional court reporter was retained to produce a transcript for both days of the workshop. Presenters were provided the opportunity to review and edit their portions of the transcript. A professional science writer was retained to attend the workshop and prepare draft presentation summaries based on the transcript and the slides displayed at the workshop. The presenters were then provided the opportunity to review and edit the draft summaries of their presentations. Occasionally, presenters inserted post-workshop information for purposes of clarification and/or adding insights. The TQA Editorial Committee reviewed and edited the presentation summaries to ensure clarity, and then prepared this report.

It is expected there will be continuing dialogue about workshop topics among workshop participants and other interested parties, and more TQA follow-up workshops are expected in 2018 and beyond.

2

NEW ERA IN COMMERCIAL AVIATION

2.1 Welcome—Opening Remarks

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

Workshop attendees were welcomed with these opening remarks on behalf of the National Academy of Engineering.

Alton Romig began by noting that he has a particular interest in this aviation-focused "Quieter America" workshop, as his pre-NAE career focused on a range of aviation-related activities at Lockheed Martin. He was manager of Lockheed's Skunk Works® and, before that, spent much of his career with the Department of Energy's Lockheed-run Sandia National Laboratories.

By way of introduction to the National Academies, Dr. Romig explained that the National Academy of Sciences was founded under congressional charter by Abraham Lincoln in 1863 to provide the government with independent, objective, expert advice related to science and technology. The National Academy of Engineering was established in 1964 and the National Academy of Medicine (originally the Institute of Medicine) in 1970. The National Academies are independent organizations, funded predominantly by government grants that function largely at the request of federal organizations to help inform policies and public opinion and to otherwise advance the pursuit of science, engineering, and medicine.

The National Academy of Engineering also conducts programs, studies, and workshops in support of the engineering profession and a variety of areas relevant to engineering practice and education. The first noise-related NAE workshop, in 2005, led to the publication of *Technology for a Quieter America*. The noise-related workshops that have followed from that report now serve as the model for a series of NAE member–inspired activities.

Dr. Romig noted that he is particularly interested in efforts to reduce aviation noise on both a personal and professional level: now that he lives near Reagan National Airport, he often hears airplanes overhead. So, while he appreciates the progress to date, such as the replacement of Stage 2 aircraft with newer, quieter planes, he looks forward to continued advances in this area.

2.2(a) Current Status and Goals of the Workshop

(Presenter 1 of 2)

Jay Dryer—*NASA*

These opening remarks stressed the benefits to NASA from NAE studies and workshops, the importance of these opportunities for the community to come together, and the significance, in particular, of this commercial aviation workshop.

Tremendous progress has been made over the last several decades in the area of noise associated with jet aviation. Despite significant reductions in jet noise levels, however, substantial challenges remain that must be addressed if the aviation industry is to continue to grow to its full potential.

NASA is working diligently on noise from the technology standpoint, stressed Dryer, Director of the agency's Advanced Air Vehicles Program of the Aeronautics Research Mission Directorate. During the workshop, Dryer would share some of NASA's exciting projects from the airframe, engine, and vehicle perspectives. For example, in partnership with the commercial aviation community, multidimensional studies are being undertaken with a holistic view that considers efficiency, noise, and economics alike.

Discussion and knowledge exchange during this workshop on aviation noise will help "make us smarter about the problem and the issues that we face," Dryer said, which in turn promises to consequentially inform decision-making.

2.2(b) Current Status and Goals of the Workshop

(Presenter 2 of 2)

James Hileman—*FAA*

The time is now to deal with aircraft noise if the growth of aviation is to be promoted in the United States, as well as abroad. Noise issues represent a major constraint on this growth, and the aviation industry—and airport neighbors—are among those sharing the view that aviation noise is a topic in great need of attention.

Hileman, the FAA's Chief Scientific and Technical Advisor for Environment and Energy, began his remarks by holding up the workshop as a key opportunity for experts to exchange ideas about the aircraft noise problem. Hileman posed some food for thought: What benefits could various community sectors gain from a step-change improvement in noise through advancements in technology? What is the business case for investing in these improvements?

The substantial progress made over the last 30 to 40 years has come about because technological improvements achieved noise reduction gains alongside fuel burn improvements. Can this type of joint progress continue? The FAA is dealing with associated short-term issues, as well as long-term technology solutions, which Hileman and others would elaborate on later in the workshop.

2.3 A Brief History of Aviation

Eric Wood—*Acentech Incorporated*

This introductory discussion of aviation history provided an important frame of reference for the workshop, setting the stage for its primary focus on the future of commercial aviation and the leadership role of the United States in the industry's continuing evolution.

Eric Wood opened his overview of aviation's history in the United States by showing his piece of the preserved fabric (Figure 2.3-1) that covered the "Wright Flyer" airplane. The first flight of this Wright Brothers plane, in Kitty Hawk, North Carolina, on Dec. 17, 1903, marked the birth of heavier-than-air aviation in the United States.

Turning attention to the early days of military aviation—during the World War I era, in particular—Wood spoke about the oil paintings by noted French artist Henri Farré that documented this period in aviation. Many of the painter's works can be seen on display at the U.S. Air Force Academy in Colorado, as well as at the Pentagon and the National Air and Space Museum in Washington, D.C. The Farré painting in Figure 2.3-2 depicts early naval aviation, showing in particular a French "hydroaeroplane" destroying a submarine in the North Sea.

Next, Wood showed the painting in Figure 2.3-3, of Edmond Genet, the first American pilot killed during WWI, and Eugene Bullard, the world's first black military pilot. Both aviators flew in the Lafayette Escadrille with American volunteer pilots assisting in the defense of France.

Moving to a 1927 photograph of the Travel Air open cockpit biplane with an OX-5 engine, as shown in Figure 2.3-4, Wood noted that this early plane was owned and operated by the Harvard Flying Club out of the East Boston Airport (now Logan International Airport).

Wood then moved his focus forward in time, showing photographs of two more advanced passenger planes, as seen in Figure 2.3-5. About the twin-engine propeller-driven Douglas DC-3, Wood explained that passengers walked "uphill" after entering through the rear door to get to their seats. The other plane shown, the four-engine propeller-driven Lockheed Constellation (the "Connie"), had three vertical tails, Wood pointed out.

Referencing Figure 2.3-6, the speaker mentioned that, on Oct. 14, 1947, Bell X-1 pilot Chuck Yeager became the first to exceed the speed of sound in level flight. The breakthrough was made possible by contributions from both industry and government.

Wood next spoke of the Oct. 26, 1958, Pan Am flight from New York's Idlewild Airport (now John F. Kennedy International Airport) to London that marked the beginning of commercial jet passenger traffic in the United States. In association with this flight, considerable noise-related efforts were undertaken by various company engineers—representing Boeing, Pratt & Whitney, and Bolt Beranek and Newman, for example—working with the Port of New York Authority (as the body was called at the time).

Going forward, the development of high-bypass engines contributed to both reduced fuel burn and reduced noise. One example is Pratt & Whitney's JT9D engine, which following considerable sea-level static testing, took its first flight test out of Bradley Field in Windsor Locks, Connecticut, in June 1968, slung under the wing of a B-52. This first time in flight is captured in Figure 2.3-7. The first flight of the Boeing 747 with four JT9D engines departed from Everett

ACENTECH

Field near Everett, Washington, on Feb. 9, 1969, with Jack Waddell in the left seat. Another example of high-bypass engines is the GE family of CF6 turbofans, Wood added.

Fast-forwarding to another decade, Wood showed images of the first supersonic passenger service by Air France and British Airways airplanes that began on Jan. 21, 1976. See Figure 2.3-8.

The presenter mentioned that commercial aircraft are already achieving incredible global transportation service, unprecedented transportation safety, and better fuel efficiency, with considerably less noise—and that more advances are on the horizon. These advances, Wood said, would be covered during the workshop.

Wood touched on efforts by Tom Sofrin and John Tyler of Pratt & Whitney to better understand the generation and propagation of noise from engine inlets and, most important, to consider what could be done to address it. He also mentioned the removal of noise-producing inlet blow-in doors and inlet guide vanes.

Low-bypass ratio engines, and later high-bypass-ratio engines with large-diameter fans, have improved performance and reduced noise, Wood stated, highlighting an example of this evolution in engine bypass ratios as shown in Figure 2.3-9. Additional progress in reducing noise is exemplified by fan discharge short ducts, followed by long ducts, the speaker stated.

Wood noted that Jack McCann at Pratt & Whitney, along with others at Boeing and Douglas, had worked with NASA, in government cooperation programs, developing effective acoustic liners installed along engine inlets and fan bypass ducts. An early example of a honeycomb perforated liner above a solid backing layer was demonstrated to achieve enhanced absorption at the frequencies needed from the fan.

Wood mentioned fan blade research toward improving performance and maintaining structural integrity, while simultaneously reducing both forward- and aft-radiated noise from the fan.

Wood also described other noise abatements, in areas such as:

Hush Kits. These were developed as add-ons to reduce engine noise radiation.

Flight Operations. Examples include thrust reductions, noise abatement turns, and scheduling.

Residential Sound Insulation. This insulation's goal is to reduce noise inside neighboring homes.

Wood's aviation history presentation concluded with an audio presentation file produced by the U.S. DOT's Volpe National Transportation Systems Center. Workshop attendees heard relative comparisons of the takeoff noise from five early planes and more recent ones, as listed in Figure 2.3-10. Readers of the pdf version of this report can access and hear the AV file by following these instructions. Consider first turning up the volume of your speaker. Double click on the lower image in Figure 2.3-10. Click on "Open". The file will open in Power Point. Go to "Slide Show" mode. After a few seconds, the five AV files should start. The audio is not calibrated to a specific level, but relative differences between aircraft are valid to compare.

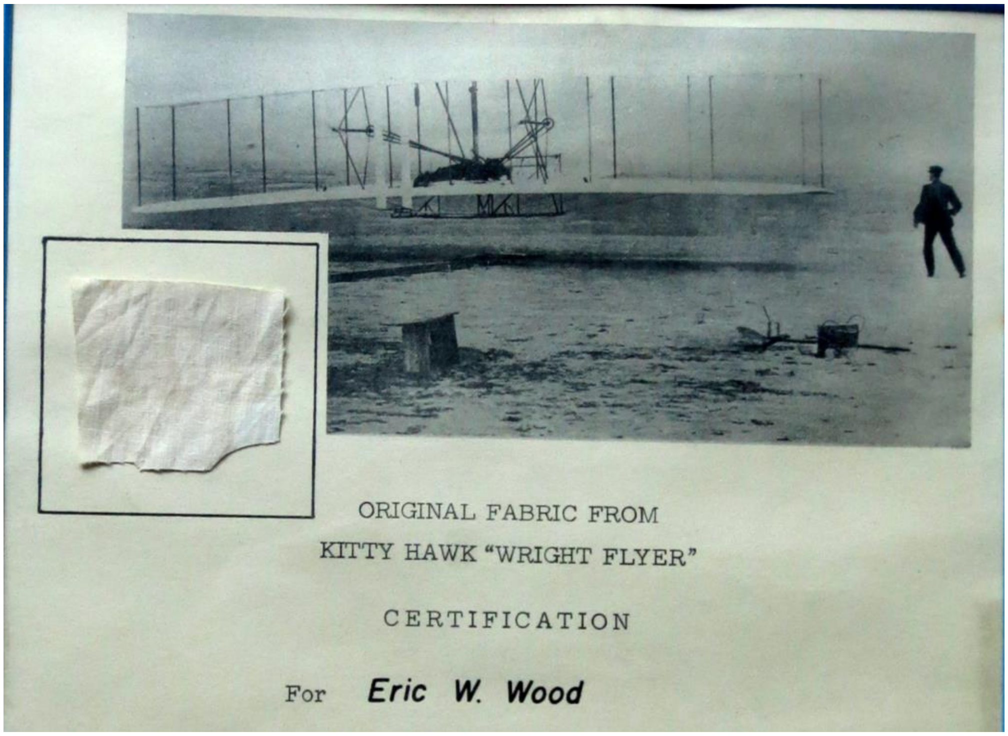


Figure 2.3-1 *Original Fabric from Wright Flyer*

Figure 2.3-2 *French hydroaeroplane destroys a submarine in the North Sea (Farré)*

Figure 2.3-3 *Edmond Genet, the first American pilot killed during WWI, and Eugene Bullard, the world's first black military pilot.*

Figure 2.3-4 *Travel Air open cockpit biplane with OX-5 engine that was owned and operated by the Harvard Flying Club out of East Boston Airport*

Figure 2.3-5. *Twin-engine propeller-driven Douglas DC-3 and four-engine propeller-driven Lockheed Constellation*

Figure 2.3-6. *Chuck Yeager, pilot of the Bell X-1 airplane, was the first to exceed the speed of sound in level flight, Oct. 14, 1947*

Figure 2.3-7 *JT9D engine slung under the wing of a B-52 in its first flight test out of Bradley Field in June 1968*

Figure 2.3-8 *First supersonic passenger service by Air France and British Airways that started on Jan. 21, 1976*

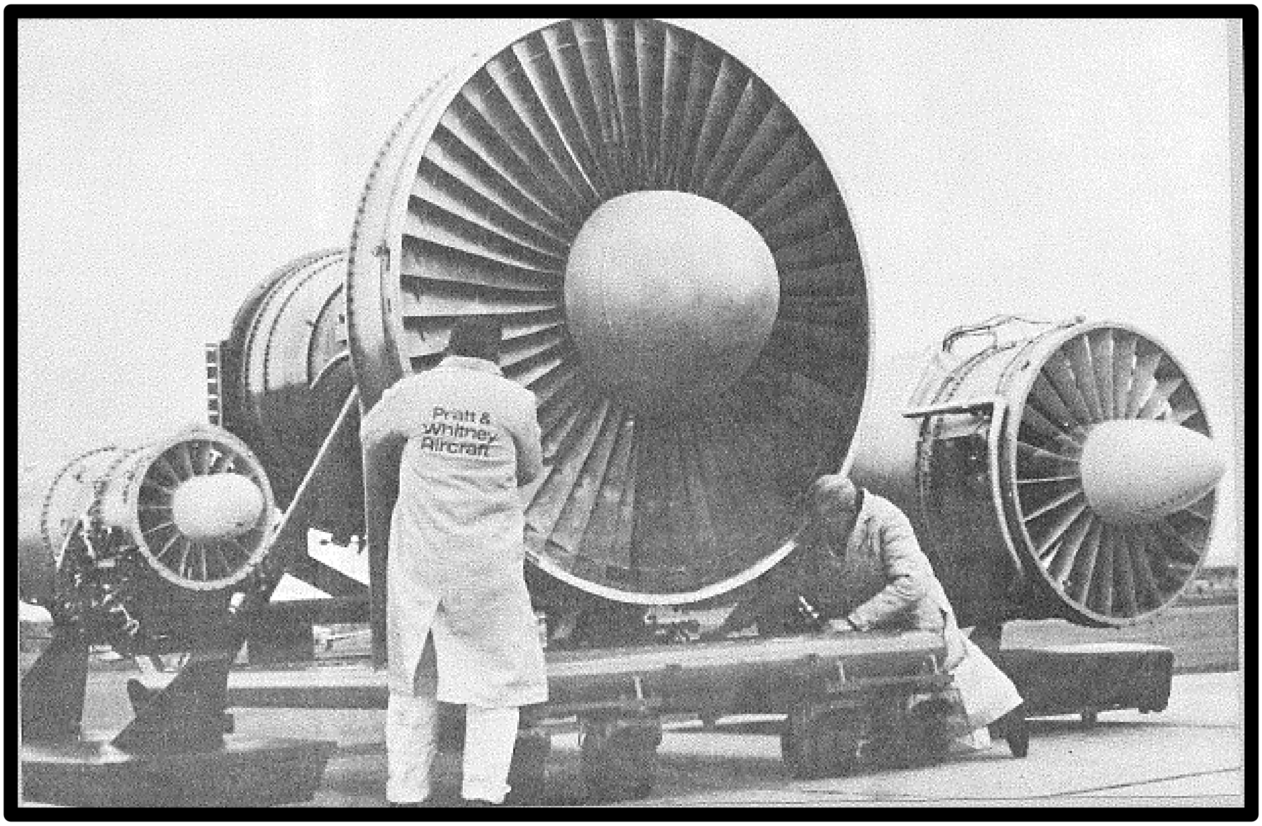
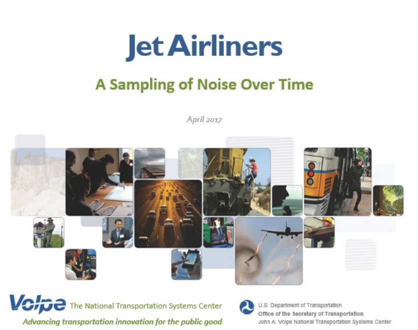


__Figure 2.3-9__ Evolution in engine bypass ratio: improved performance, reduced noise

Aircraft	Noise Level, dBA 1000 ft	Reduction dB	Date
B707	110		1959
B727	108	2	1968
MD81	99	11	1980
B777	95	15	1995
B787	91	19	2011

__Figure 2.3-10__ Audio demonstration compares departure noises from five early jet airliners, and recent ones, listed above. Left click the image below to download a presentation with audio samples from these jet airliners. Click the "Slide Show" tab, then click "From Beginning." The audio samples will begin.



2.4 Effects of Aviation Noise on Humans: Learning, Sleep, Quality of Life

Mathias Basner—*University of Pennsylvania*

Aircraft noise is associated with consequences such as community annoyance and effects on children's cognitive performance; sleep; and many studies indicate cardiovascular health. Research has shed some light on the short- and long-term health consequences of noise, but additional, up-to-date research is sorely needed to understand these effects more fully.

Speaker Mathias Basner from the University of Pennsylvania opened his discussion of the effects of aviation noise by highlighting some basic background about noise—for example, the fact that noise has both an objective and subjective component, with the objective aspect involving physical noise level and sound's spectral composition. Some data from both perspectives is reflected in Figure 2.4-1. While acknowledging the well-known health consequence of noise-induced hearing loss, the speaker focused his presentation on nonauditory health effects.

The World Health Organization published a report in 2011 about the disease burden associated with environmental noise. The organization concluded that, in Western European member states alone, 1.6 million healthy life years are lost annually due to environmental noise exposure. And aircraft noise is one contributing component. In this sphere, as summarized in Figure 2.4-2, the 2011 analysis found noise-induced sleep disturbance to be the strongest contributor to the health burden, followed by community annoyance, ischemic heart disease, childhood cognitive impairment, and tinnitus. Were the numbers to be updated, however, the current contribution of ischemic heart disease would likely be "substantially larger," Basner stated.

The speaker next addressed community annoyance, which he explained is most often established based on surveys. Subjects, who select in the upper 28 percent of the annoyance response scale, are typically defined as "highly annoyed." The percentage of "highly annoyed" subjects is usually plotted against an "equivalent noise level," a cumulative noise metric that averages noise exposure over a year or other period of time. In annoyance surveys, one-third of the variance tends to be explained by the noise level, with another third explained by situational variables and another by personal factors.

Findings related to community annoyance can help point the way to potential subjective noise level mitigation strategies, Basner stressed. An airport's communication strategy, for example, has the potential to lessen community annoyance.

Exposure-response functions used to assess the effects of traffic noise on community annoyance are by-and-large very out of date, Basner noted, with the average age of studies contributing to one commonly used exposure-response function is approaching 40 years as shown in Figure 2.4-3. "The aircraft noise exposure 39 years ago is not comparable to what exposed residents experience today," the speaker stated. More recent exposure-response functions show "much higher" annoyance levels at a given equivalent noise level. Some of the difference, Basner said, may be explained by airport expansion, in response to which a population may feel more affected by airport noise.

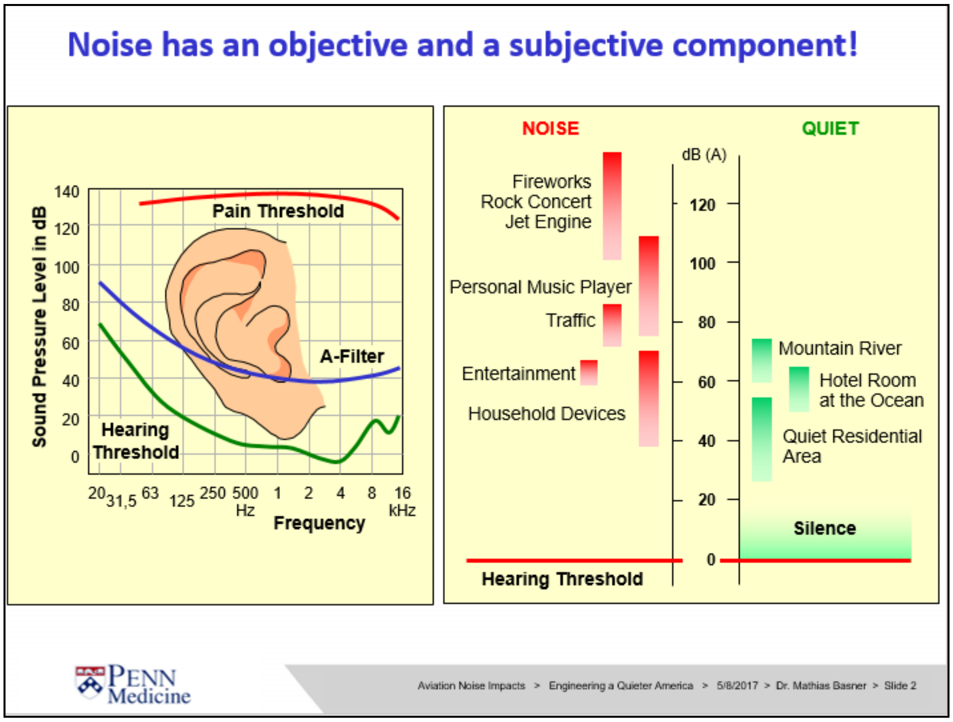
The speaker moved next to the subject of the effect of aircraft noise on cognitive performance in children. Reading performance in children has been shown in studies to decrease with increasing levels of aircraft noise, Basner said, pointing to two prominent examples of studies, as shown in Figure 2.4-4.

Turning next to noise-induced sleep disturbance, the presenter spoke of three components that determine its extent: the acoustical properties of the noise event; individual moderators such as someone's age and sensitivity to noise; and situational moderators such as a person's sleep stage and how much sleep time has already elapsed. "These three together will determine physiological reactions to single noise events," Basner said, such as autonomic arousals, increases in heart rate, awakening, sleep state changes, or body movements. Accumulated over the whole night, these arousal events determine degree of disturbance. They can result in sleep fragmentation, less slow-wave or deep sleep, more time spent in superficial sleep stages, and more time spent awake. Figure 2.4-5 speaks to these factors. "We and others were able to demonstrate next-day consequences like decreased cognitive performance or increased levels of sleepiness if sleep is relevantly disturbed by noise," Basner said. The current hypothesis, he noted, is that "if sleep is relevantly disturbed by noise for several years, this noise-induced sleep disturbance can contribute to long-term consequences such as high blood pressure and myocardial infarction."

Basner turned next to addressing the question, "How can noise lead to long-term health consequences?" The hypothesis is that noise acts as an unspecific stressor by disturbing sleep and communication and by generating annoyance. As a stress response, the body excretes hormones such as cortisol and epinephrine that can cause blood vessel coagulation and increased cholesterol levels, among other unfavorable physiological changes. One study's perspective on proposed pathophysiological mechanisms of cardiovascular disease induced by noise (as well as exposure to environmental air pollution, with which noise exposure is often co-associated) is summed up in Figure 2.4-6.

If relevant noise exposure continues over an extended time period, the unfavorable changes in blood vessels and blood parameters could contribute to negative health consequences, especially cardiometabolic disease, the speaker explained. Several meta-analyses have considered noise's cardiovascular effects, and the exposure-response functions often indicate a 5 to 10 percent increase in risk per 10 decibel increase in noise exposure. Figure 2.4-7 speaks to associations between transportation noise and cardiovascular health outcomes. While the risk is small relative to other risk factors, it is nonetheless relevant from a public health perspective, Basner noted, given the large numbers of people exposed to relevant noise levels.

In conclusion, the presenter summarized results from noise effects researchers investigating the subjects of aircraft noise and community annoyance, children's cognitive performance, sleep disturbance, and cardiovascular disease risk. "We need current and precise exposure response functions, representative of the affected population, to inform noise policy in general and limit values more specifically," Basner said. In closing, he pointed out that the World Health Organization (WHO) plans to publish revised environmental noise guidelines later in the year. The new WHO document will address evidence emerging since the year 2000, which Basner believes will be "very influential."



Basner M, Babisch W, Davis A, et al. Auditory and non-auditory effects of noise on health. Lancet 2014;383(9925):1325-32. with permission

Figure 2.4-1 *Components of Noise: Objective, Subjective*

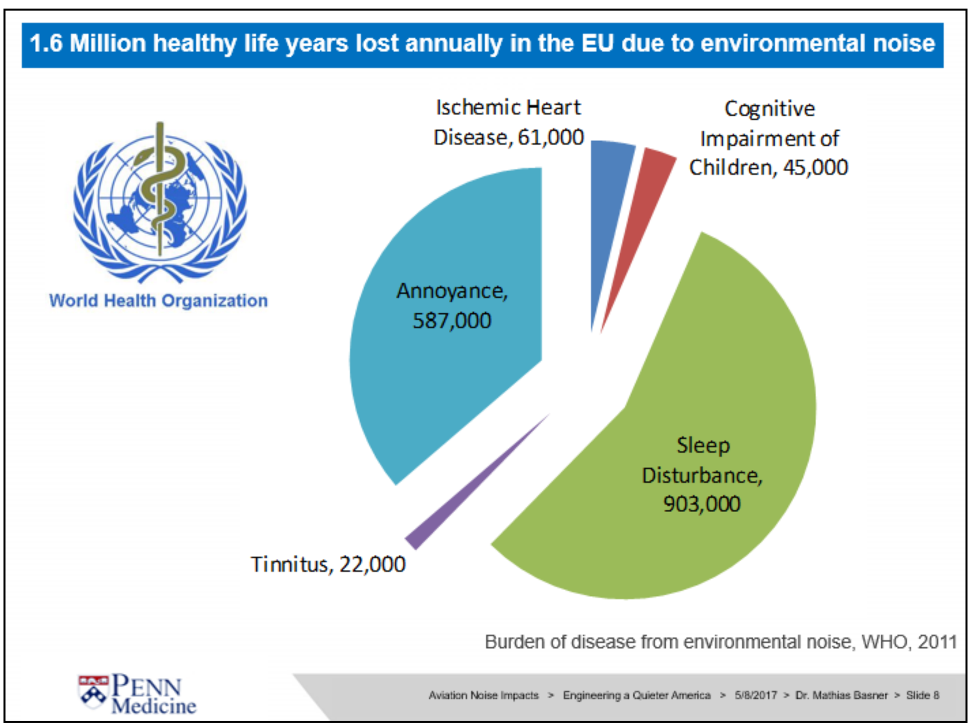
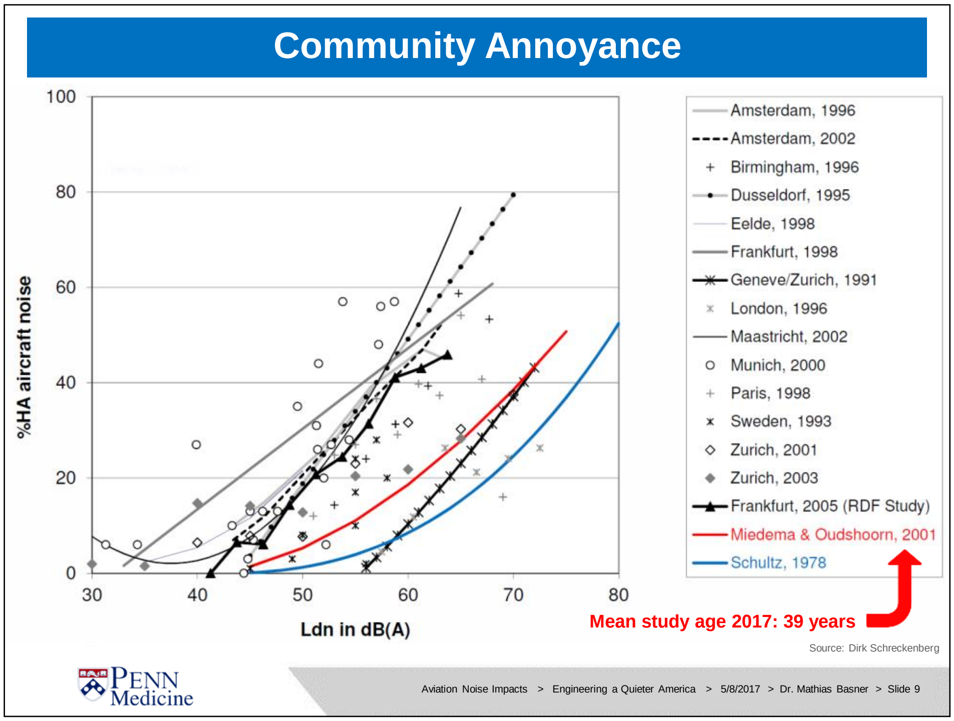
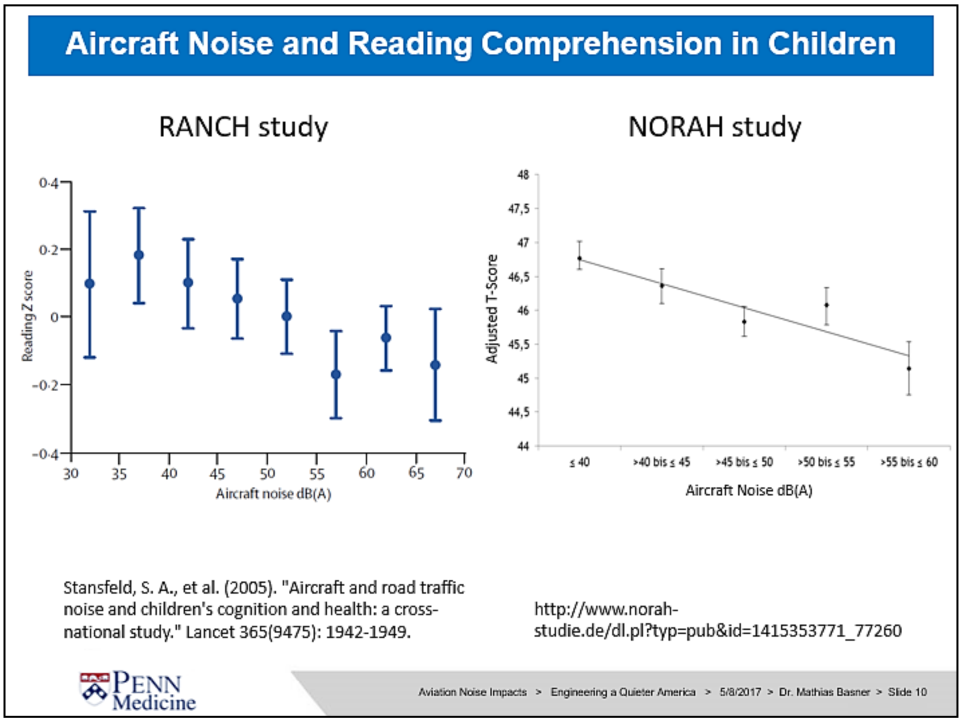


Figure 2.4-2 *WHO Findings: Burden of Disease From Environmental Noise*



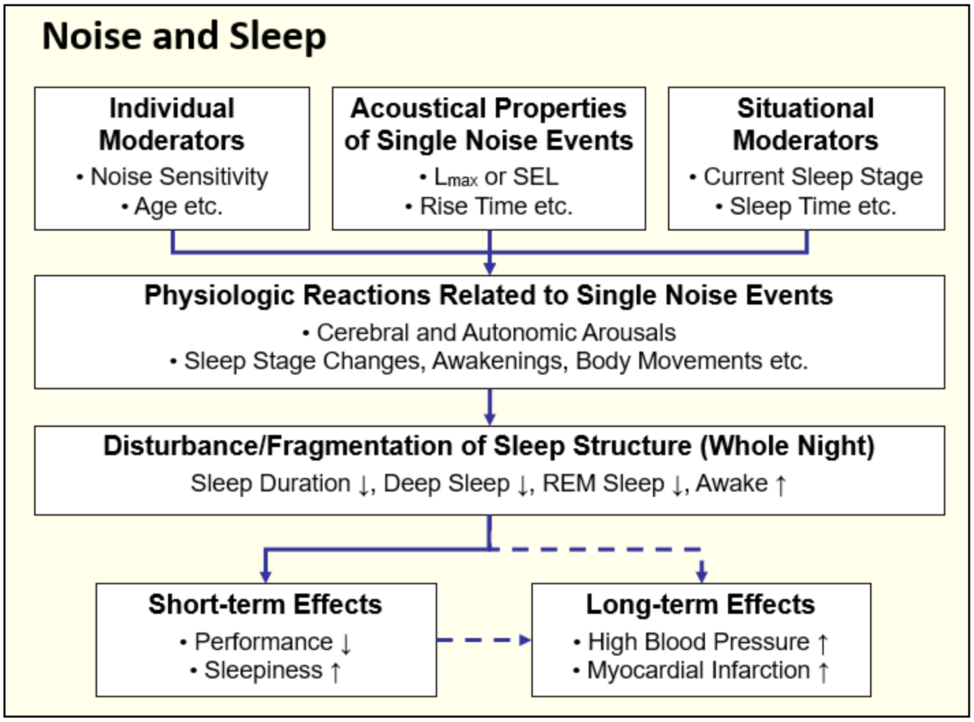
Source: Dirk Schreckenberg & RIVM

Figure 2.4-3 *Community Noise-Exposure Response Study Results*



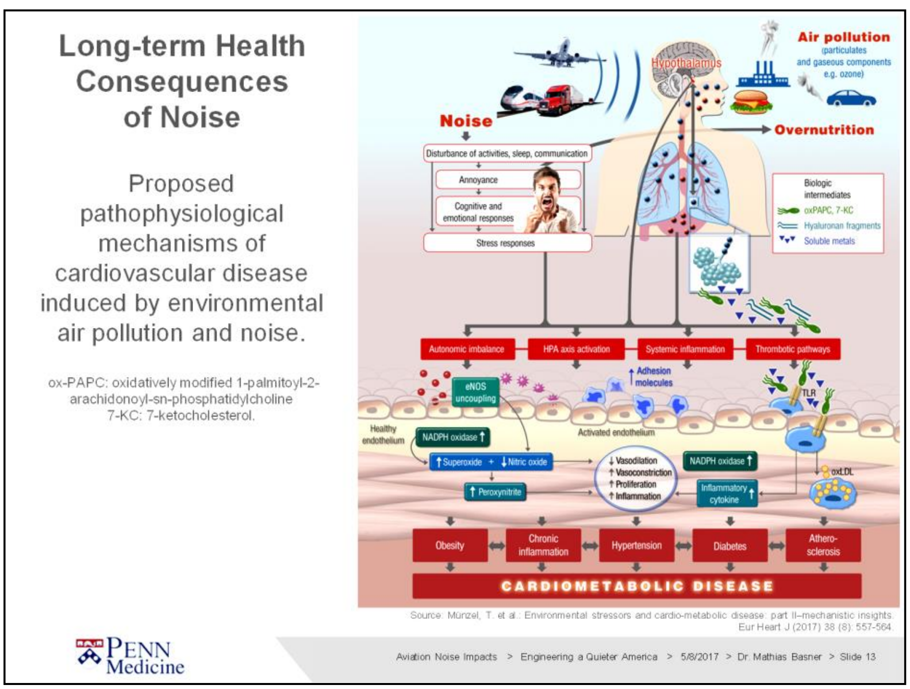
SA Stansfeld,B Berglund,C Clark, et al. Aircraft and road traffic noise and children's cognition and health: a cross-national study. Lancet 2005: 1942-49. with permission

Figure 2.4-4 *Effects of Aircraft Noise on Children's Reading*



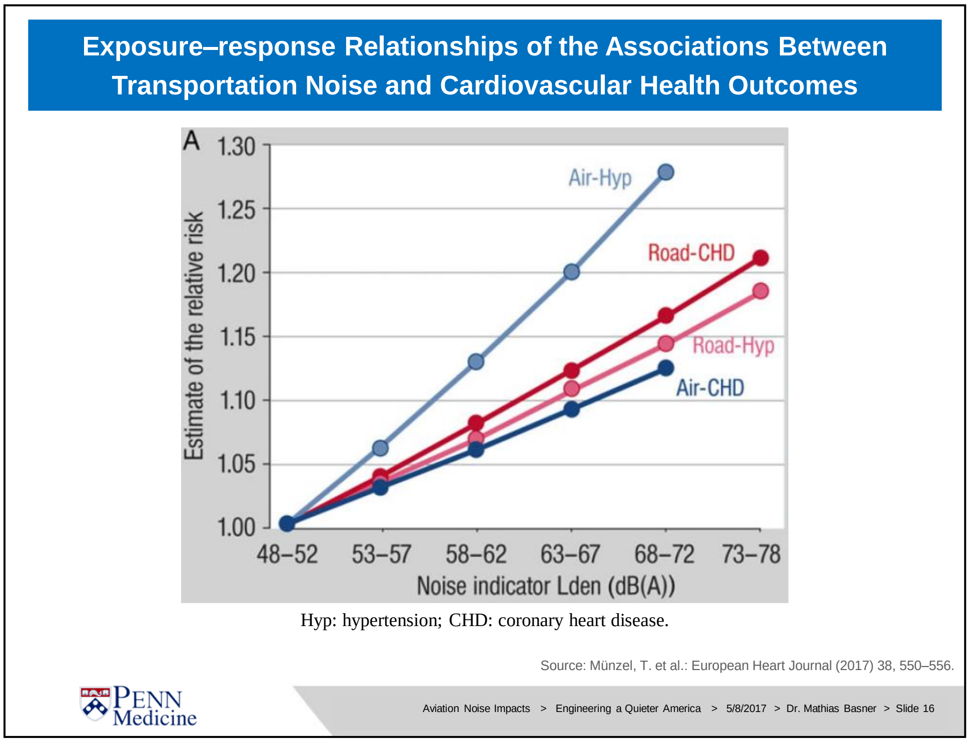
Basner M, Müller U, Griefahn B. Practical guidance for risk assessment of traffic noise effects on sleep.
Appl Acoustics 2010;71(6):518-22. with permission

Figure 2.4-5 *Noise and Sleep: Factors and Consequences*



Münzel, Thomas; Sørensen, Mette. Environmental stressors and cardio-metabolic disease Part II.
European Heart Journal 2017. Oxford University Press. with permission

Figure 2.4-6 *Proposed Mechanisms for Cardiovascular Disease as a Consequence of Noise*



Münzel, Thomas; Sørensen, Mette. Environmental stressors and cardio-metabolic disease Part I. European Heart Journal 2017. Oxford University Press. with permission

Figure 2.4-7 *Exposure-Response Relationships: Transportation Noise and Cardiovascular Health.**

* *L_{den}, the noise indicator used is common in Europe. It is similar to L_{dn} but with a correction for noise in the evening hours.*

2.5 NextGen: Noise and the New Navigation System

John Hansman—*Massachusetts Institute of Technology*

The FAA's NextGen program, including the PBN component, introduces its own noise-associated challenges for which solutions are under study. Tools for evaluating these noise issues include new, more representative metrics and sophisticated modeling techniques, which are pointing the way to promising noise reduction options. Prospective solutions focus on factors such as climb and arrival speed, slope, and altitude and further refined flight paths.

MIT aeronautics professor John Hansman discussed NextGen, associated noise challenges, and possible solutions in the works. The program's major technical elements include area navigation, known as RNAV; performance-based navigation, or PBN; and required navigation performance, or RNP.

About RNAV, Hansman stated that more than 95 percent of the jet fleet is equipped to use this navigation method, which typically relies on GPS or a GPS inertial navigation applied to waypoints. As for RNP, advantages beyond its improved accuracy include the capability to program the entire flight path, including vertical profiles. Vertical precision approach RNP often requires special crew training, Hansman explained, and the U.S. jet fleet is about 60 to 70 percent equipped with this capability.

With RNAV arrival and departure procedures, noise has been concentrated and community complaints have increased under affected flight tracks. The 65 DNL contour has shrunk and largely limited the higher noise levels to areas below the RNAV flight tracks. However, as the presenter emphasized, the traditional noise metric fails to adequately capture concerns by some neighbors—particularly at high concentrations of flights.

With complaints coming largely from outside the 65 DNL contour area, alternative metrics should be considered, Hansman stated. When considering modifications to arrival and departure procedures, a focus is on single-event metrics, such as maximum sound pressure level, L_{max}, or sound exposure level (SEL). Another option: number-based metrics such as the number of events above a certain L_{max} level.

Attempts to improve the U.S. aviation system by procedures such as NextGen can be blocked in communities opposed to the changes by either safety processes or environmental approval processes, the speaker pointed out. PBN is an interesting prospect as a tool to actually *reduce* community noise impact.

Next, Hansman discussed noise modeling. The traditional approach relies on the aviation environmental design tool (AEDT), a noise-power-distance-based method that, while reasonable for looking at particularly significant DNL contours, does not consider factors such as velocity effects on source noise. The NASA Aircraft Noise Prediction Program (ANOPP) is a physics-based approach that looks at various noise sources—not only the engine, fan, combustion, and jet, but also the airframe.

For the performance model of an aircraft, Hansman's team uses Base of Aircraft Data (BADA) 4 model data for existing aircraft, and for future aircraft or where data is unavailable in BADA 4, they use the Transport Aircraft System Optimization (TASOPT) aircraft design and prediction program developed by Mark Drela. The procedure definition can come from radar-based or actual trajectories to provide the flight profile, based on the airplane's thrust, velocity, position, and configuration during the procedure. Finally, to generate single-event noise grids for a particular approach, ANOPP or AEDT is used.

One effect seen in AEDT, Hansman pointed out, is that with increased acceleration or climb speed, the airframe noise becomes dominant. The traditional AEDT modeling system assumes a consistent 160-knot speed, and airframe noise associated with higher speeds would not typically be captured. Options for adjusting typical departure procedures to address noise issues include: using a maximum performance climb—getting the airplane as high as possible and mitigating noise downstream. Altitude can be reduced; thrust reduction height can be increased for a higher climb; or acceleration height can be increased or acceleration adjusted.

Hansman discussed the result of going to maximum climb thrust, maintaining 160 knots, to maximize altitude. Pointing to the example of L_{max} contours for the 737-800, Hansman stated that, compared with baseline noise contours using the standard departure profile out of Boston, the high thrust level widens but shortens the noise contour. Under the flight track, noise mitigates as one goes further downstream. The more promising approach was "delayed acceleration climb," in which the aircraft accelerated to 180 knots at 1,000 feet rather than accelerating to the baseline of 250 knots. The width of the contour was unchanged near the airport but shrank along the flight path. Looking at a parametric sweep, noise improves even more at 200 knots, but starts to become noisier again at 220 knots. With the larger 777-300, noise contours narrow along the track, although not by as much as for the 737. "So this looks like it has some promise, and is one thing that we're pursuing," Hansman said.

Hansman's team is also studying dispersion of departure routes as an alternative for reducing noise impact. A Standard Instrument Departure "Open SID" procedure involves a departure flight path that begins over a low-impact area and is adjusted so the plane is redirected to a downstream waypoint, re-introducing the previous natural dispersion. Another option being examined is a steep one-segment or two-segment approach. The steeper the glide slope, the more L_{max} mitigation can be achieved. But these high-energy, steeper glide slopes also come with significant operational safety concerns that must be addressed, Hansman stressed.

Next, the speaker briefly discussed noise preferential lateral paths associated with PBN, based on flying over areas with minimal noise impact or high ambient noise levels. Hansman used the example of a "White House" RNAV GPS approach at Logan Airport, which moves the contours away from population areas. For operational reasons associated with the mixing of aircraft using differing approach procedures, these paths tend to be used at night.

Hansman closed by speaking about ambient noise—from highways, for example—for masking aviation noise. The approach shows promise but presents its own challenges. For example, the expected width of the aviation noise contour can be significantly larger than that for the highway contour. And in some scenarios, significantly more people may actually experience noise at the 60 or 65 dB L_{max} level.

2.6 Economic Impact of Air Transportation

2.6(a) Economic Impact of Air Transportation
(Presenter 1 of 2)

Liying Gu—*Airports Council International–North America*

U.S. airports make a substantial economic impact. A recent Airports Council International (ACI) report found that U.S. commercial airports support nearly 10 million jobs and a $358 billion annual payroll. But traffic originating from North America airports is seeing significant losses in their market share, with world aviation moving eastward and areas such as the Asia-Pacific region experiencing much faster growth in passenger traffic. Continuous capital investment is required to support needed infrastructure and keep U.S. aviation serving as a thriving "economic engine."

Liying Gu, Airport Council International's vice president for economic affairs and research, discussed the economic impact of U.S. airports, including factors such as revenue and traffic trends. Her presentation was followed by the complementary perspective of Thea Graham with the Federal Aviation Administration.

Gu began her presentation with a global airport industry overview for context. She summed up total industry revenue between 2008 and 2014 (including aeronautical revenue, non-aeronautical revenue, and in some cases non-operating revenue). As reflected in Figure 2.6(a)-1, data show $142.5 billion generated by the global airport industry in 2014, a number Gu pointed out is roughly equal to the gross domestic product (GDP) of the country of Hungary (which ranked 58th among countries/regions), according to International Monetary Fund (IMF) data for the year. For comparison, Gu added that commercial airlines generated some $751 billion total revenue in 2014, according to International Air Transport Association data. The airport industry is about one-fifth the size of the commercial airlines in terms of total revenue.

Focusing on U.S. commercial airports, Gu mentioned that they generated about $25.5 billion in total revenue in the same 2014 time frame, accounting for about 18 percent of the global airport industry's total revenue. U.S. airport industry revenue and growth are shown in Figure 2.6(a)-2. Referring to Figure 2.6(a)-3, Gu pointed out that "U.S. airports actually are operating on a very different business model than the rest of the world," with passenger-related revenue representing only 28 percent of aircraft-related revenue whereas, in other regions of the world, passenger revenue is 58 to 79 percent. The primary reason, she explained: Whereas passenger facility charge is capped at $4.50 per flight segment in the United States, the rest of the world has no cap.

Despite challenges, passenger traffic "demonstrates resilience," Gu stated, continuing to grow, and at a much higher rate than cargo traffic. See Figure 2.6(a)-4. In the 2005–2015 time frame, passenger traffic rose in absolute value by 47 percent and cargo traffic by 18 percent, while movements only grew by 1 percent, the speaker highlighted.

As shown in Figure 2.6(a)-5, worldwide traffic originating from U.S. airports decreased from 42 percent in 1997 to 22 percent in 2015—all this while the Asia-Pacific region grew from 18 percent to 34 percent in the same period. Airports in the Middle East and Latin America, as well as in the Caribbean, also grew slightly. ACI World predicts that the mature markets in North America and Europe will continue to lose their market share in the 2015–2035 time frame, with growth seen primarily in the same Asia-Pacific and Middle East markets. "World aviation has continued to move eastward," Gu said. As reflected in Figure 2.6(a)-6, by 2035, China is expected to surpass the United States and gain the top spot in terms of passenger traffic. India, Indonesia, and Vietnam are also expected to make gains. Even after recovery from the Great Recession, aircraft movements have continuously declined, primarily due to "structural changes" in the North American market (which is dominated by the U.S. market). Only six of the 30 largest U.S. airports (which represent 72.6 percent of total traffic share) had more operations in 2015 than in 2005, the presenter pointed out.

ACI recently commissioned a study on commercial airports' economic impact. As summarized in Figure 2.6(a)-7, the report found that the 485 commercial airports in the United States support 9.6 million jobs, a $358 billion annual payroll, and a $1.1 trillion annual output—making, in Gu's words, "significant contributions" to the national economy. The nation's commercial airports are associated with nearly 1.2 million airport jobs. Visitor spending supports another 4 million jobs, while related construction employed more than 50,000 workers. Direct economic impact from these airports exceeds $256 billion annually, with another $12 billion added to the national economy by construction projects. Multiplier impacts result from the re-circulation and re-spending—and sometimes multiple occurrences of re-spending—the speaker said. Direct, multiplier, and total economic impacts are summarized in Figures 2.6(a)-8, 2.6(a)-9, and 2.6(a)-10, respectively.

The speaker addressed the question of how the U.S. aviation industry can continue to serve as an economic driving force. The answer, she said, is continuous capital investment. ACI recently released a study estimating total airport infrastructure needs in the 2017–2021 time period. The report estimated the need at about $100 billion when adjusted for inflation, which amounts to about a 32 percent increase over the previous study of the 2015–2019 time frame. Predicted needs are shown in Figure 2.6(a)-11. Factors to which the increase is attributed, Gu explained, include the need to operate aging infrastructure, a recovering U.S. economy, increased traffic demands, and airline consolidation and concentration in hub operations.

Speaking to funding sources for these infrastructure needs, Gu identified the largest funding source as airport-generated net income and the second largest as the FAA Airport Improvement Program, with its $3.35 billion current annual grant.

In conclusion, the speaker called airports "a significant economic engine, not only locally and nationally, but also globally," and added, "Airports continue to grow and provide economic vitality to their communities."

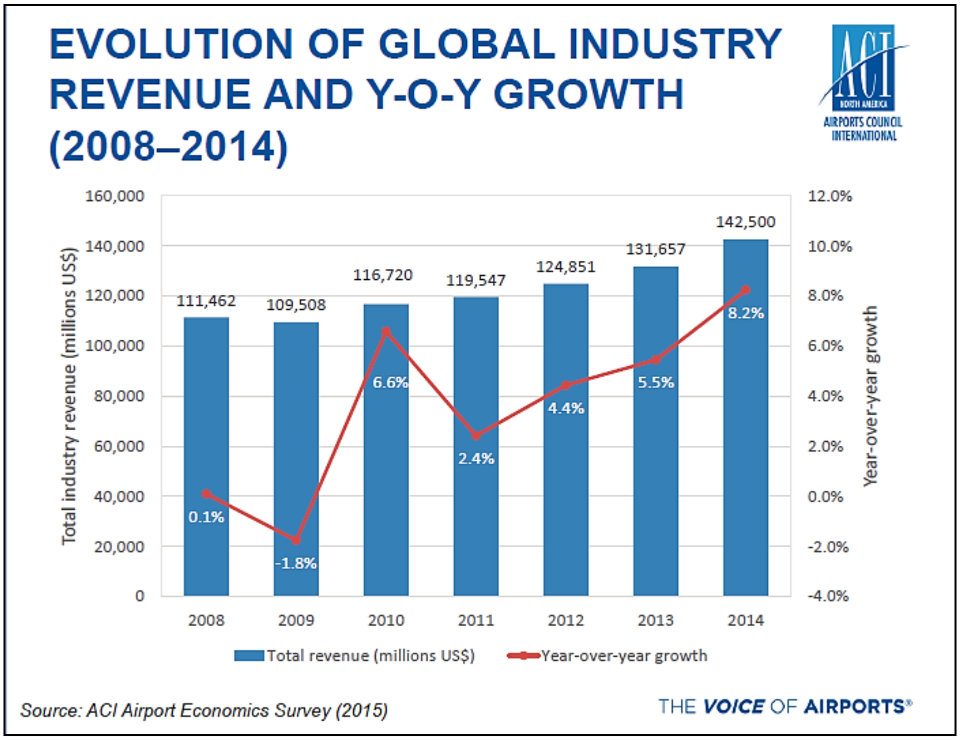


Figure 2.6(a)-1 *Global Airport Industry Revenue, 2008–2014*

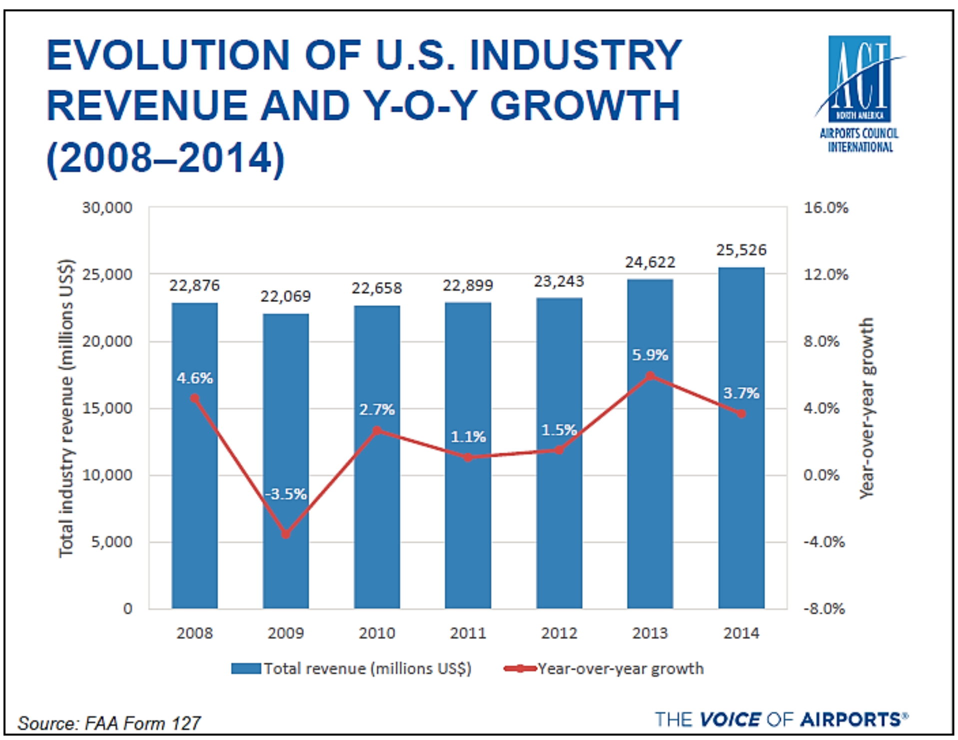


Figure 2.6(a)-2 *U.S. Commercial Airport Industry Revenue, 2008–2014*

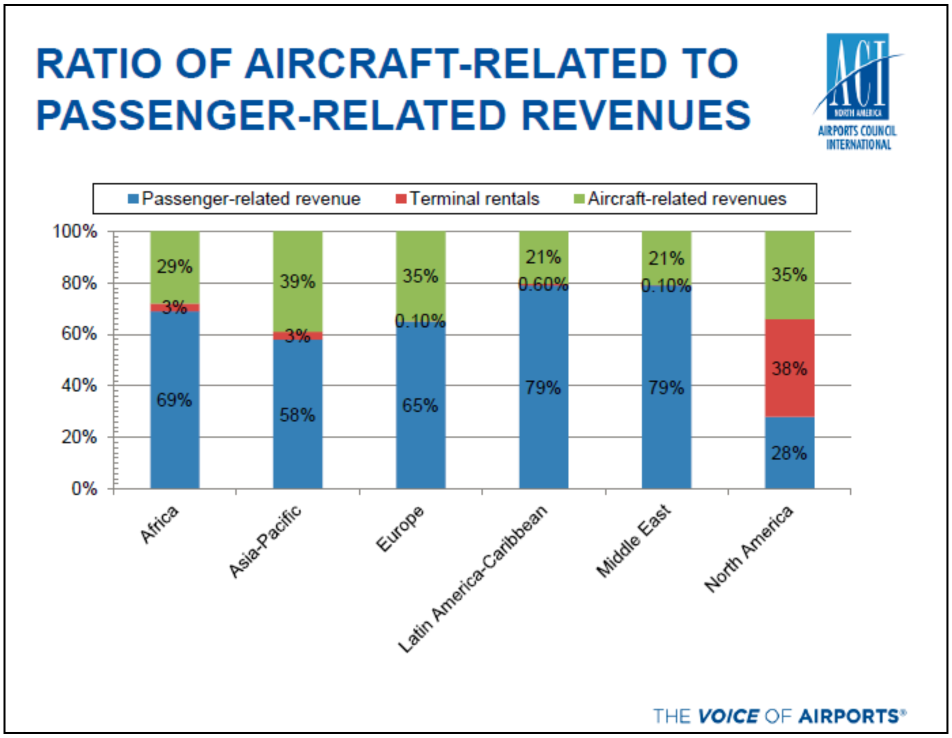


Figure 2.6(a)-3 *Ratios of Aircraft-Related to Passenger-Related Revenues*

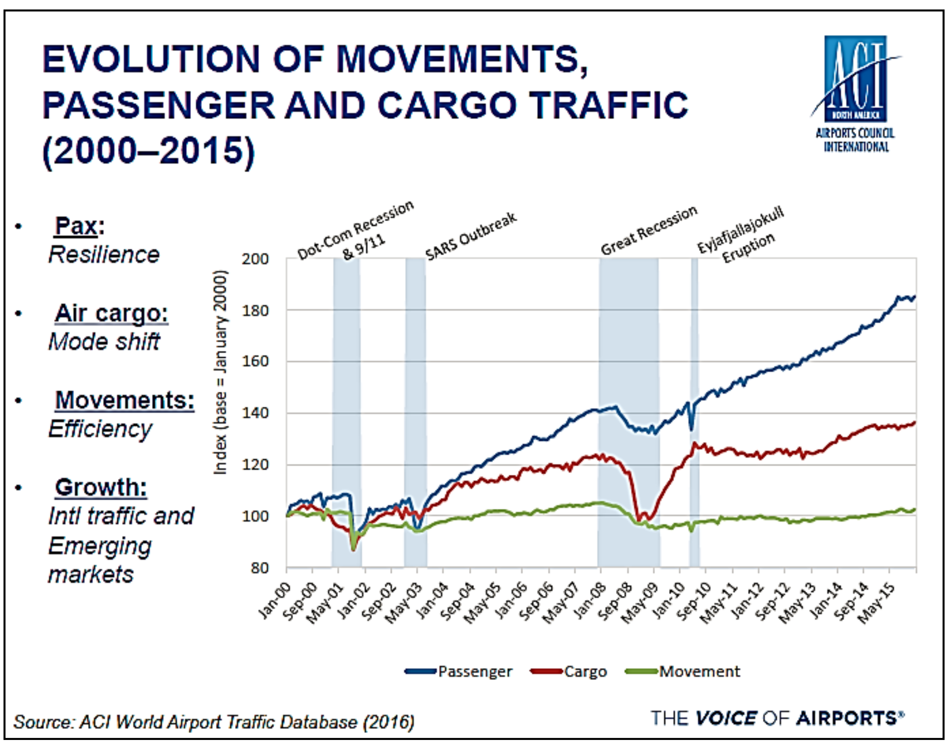


Figure 2.6(a)-4 *Growth in Passenger and Cargo Traffic, 2000–2015*

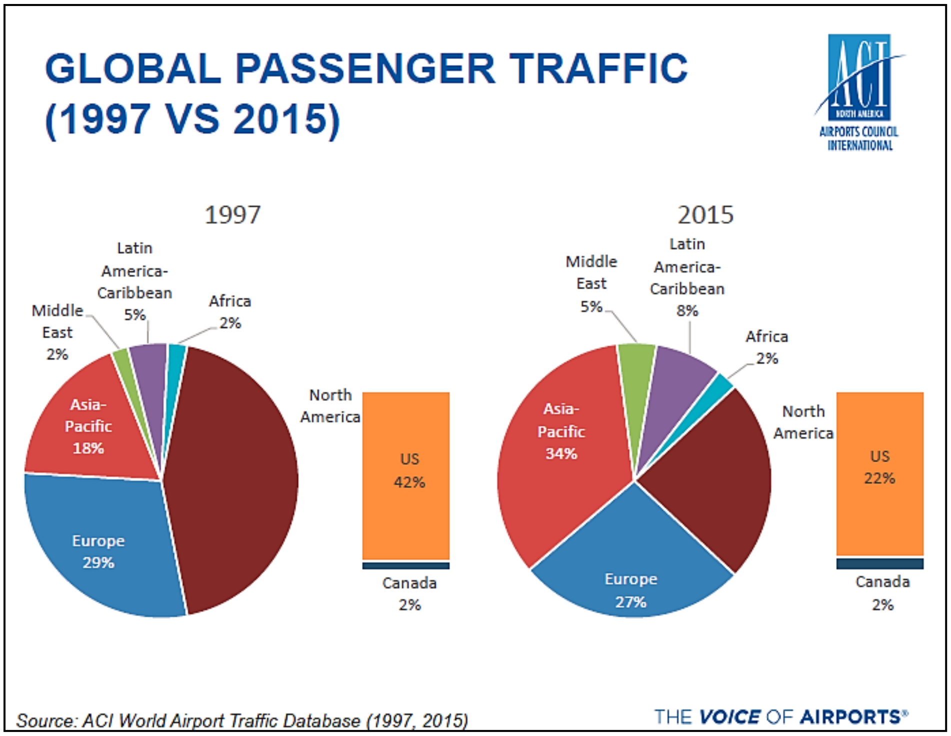
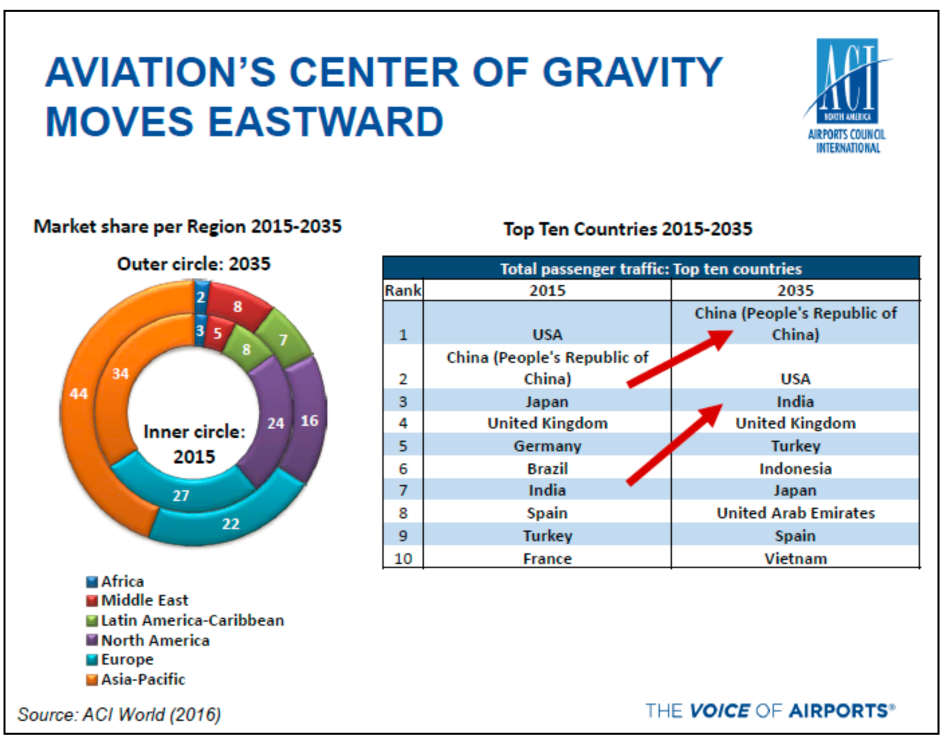


Figure 2.6(a)-5 Global Passenger Traffic Around the World—1997 vs. 2015



Total passenger traffic: Top ten countries		
Rank	2015	2035
1	USA	China (People's Republic of China)
2	China (People's Republic of China)	USA
3	Japan	India
4	United Kingdom	United Kingdom
5	Germany	Turkey
6	Brazil	Indonesia
7	India	Japan
8	Spain	United Arab Emirates
9	Turkey	Spain
10	France	Vietnam

Figure 2.6(a)-6 Market Share by Country, 2015 vs 2035 Projections

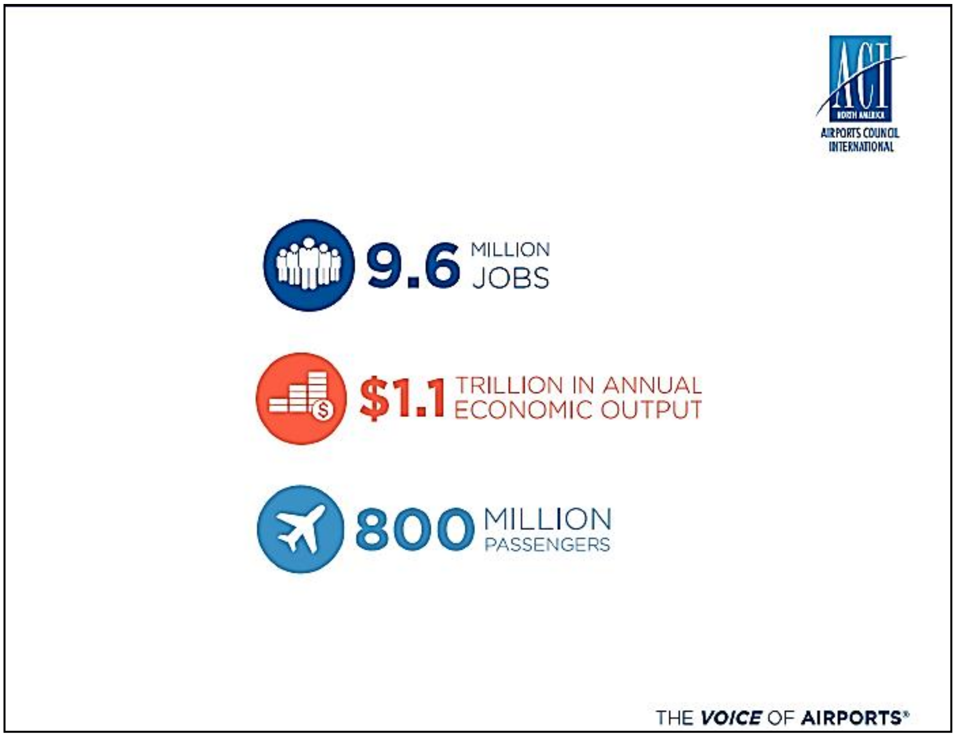


Figure 2.6(a)-7 *ACI Report Findings: U.S. Commercial Airports' Economic Impact*

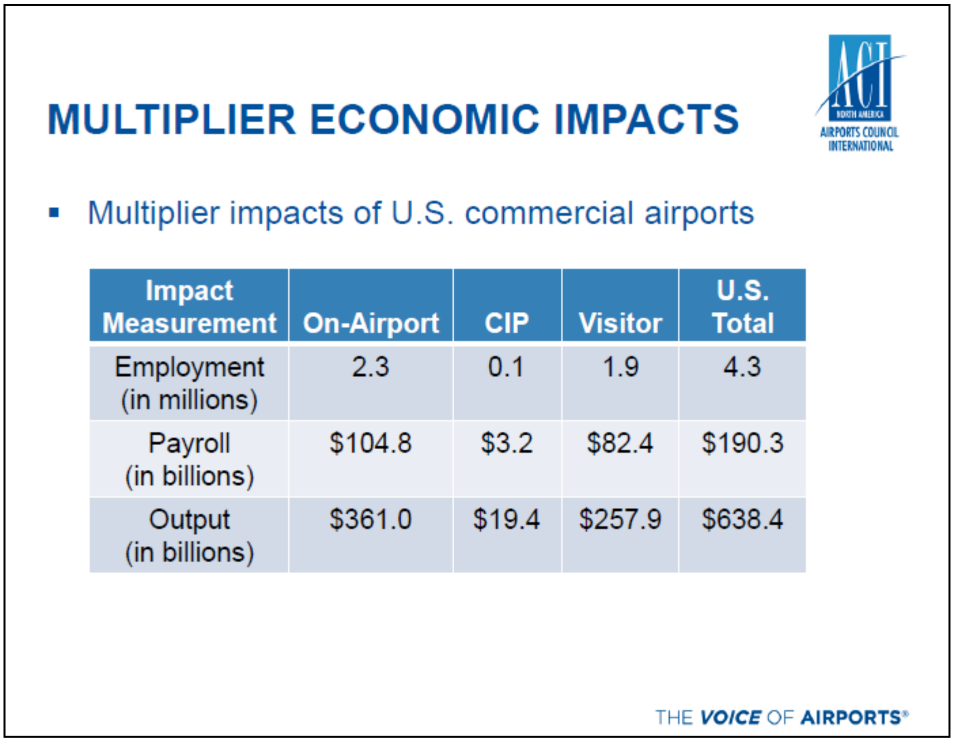
DIRECT ECONOMIC IMPACTS

- Direct impacts of U.S. commercial airports

Impact Measurement	On-Airport	CIP	Visitor	U.S. Total
Employment (in millions)	1.2	0.1	4.1	5.3
Payroll (in billions)	$72.3	$1.9	$93.4	$167.6
Output (in billions)	$256.6	$12.2	$228.1	$496.8

THE VOICE OF AIRPORTS®

Figure 2.6(a)-8 *U.S. Commercial Airports' Direct Economic Impacts*



MULTIPLIER ECONOMIC IMPACTS

- Multiplier impacts of U.S. commercial airports

Impact Measurement	On-Airport	CIP	Visitor	U.S. Total
Employment (in millions)	2.3	0.1	1.9	4.3
Payroll (in billions)	$104.8	$3.2	$82.4	$190.3
Output (in billions)	$361.0	$19.4	$257.9	$638.4

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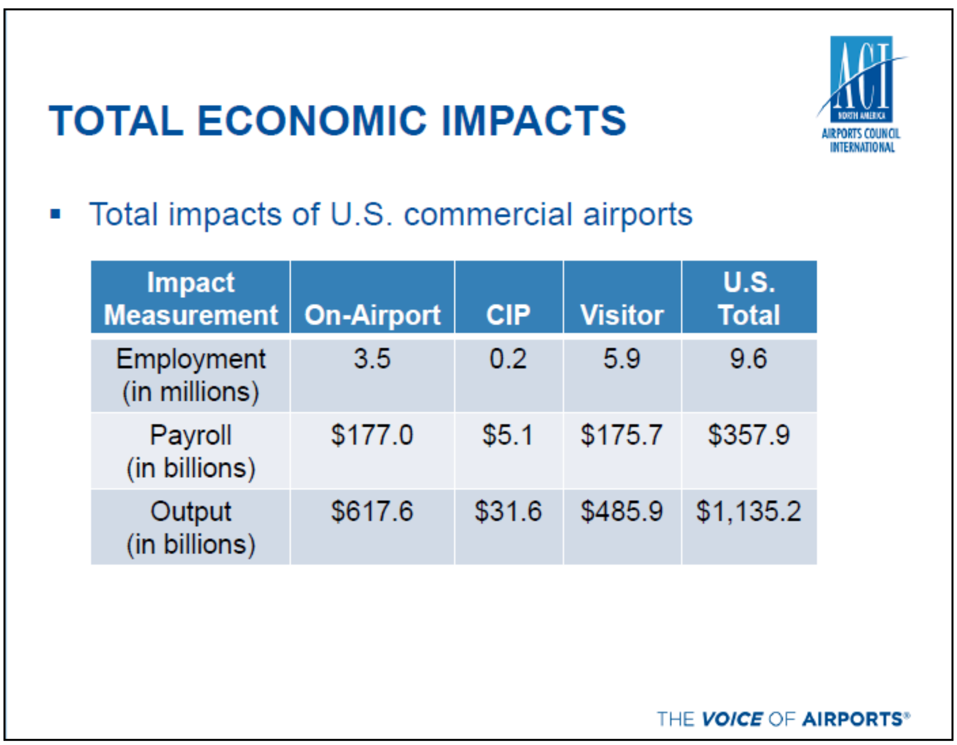
Figure 2.6(a)-9 *U.S. Commercial Airports' Multiplier Economic Impacts*



TOTAL ECONOMIC IMPACTS

- Total impacts of U.S. commercial airports

Impact Measurement	On-Airport	CIP	Visitor	U.S. Total
Employment (in millions)	3.5	0.2	5.9	9.6
Payroll (in billions)	$177.0	$5.1	$175.7	$357.9
Output (in billions)	$617.6	$31.6	$485.9	$1,135.2

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Figure 2.6(a)-10 *U.S. Commercial Airports' Total Economic Impacts*

ACI-NA ESTIMATES $100 BILLION INFRASTRUCTURE NEEDS FROM 2017 TO 2021

In Millions of Current Year Dollar	2017	2018	2019	2020	2021	Total
Large	$ 12,627	$ 13,502	$ 13,778	$ 10,929	$ 9,539	$ 60,375
Medium	$ 2,376	$ 2,766	$ 2,545	$ 1,953	$ 2,078	$ 11,718
Small	$ 1,748	$ 1,871	$ 1,713	$ 1,485	$ 1,665	$ 8,483
Non-hub*	$ 1,068	$ 1,084	$ 1,100	$ 1,117	$ 1,134	$ 5,504
Other*	$ 2,677	$ 2,717	$ 2,757	$ 2,799	$ 2,841	$ 13,790
Total						**$ 99,869**

Note: Assumes a 1.5% annual increase in construction cost escalation.
* Based on FAA NPIAS data with inflation adjustment.

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Figure 2.6(a)-11 *Upcoming Infrastructure Need Estimates*

2.6(b) Economic Impact of Air Transportation

(Presenter 2 of 2)

Thea Graham—*Federal Aviation Administration*

Aviation is extremely important to the U.S. economy, and in fact civil aviation has been the top U.S. net export for more than a decade. The Federal Aviation Administration has rigorously evaluated the economic contributions of the air transportation industry and broken them down in various ways—with the common conclusion that this industry achieves an extremely far-reaching impact. "Air transportation provides a foundation for businesses and families to connect and reconnect while ensuring economic growth and prosperity."

Thea Graham, Manager of the Economic Analysis Group in the Federal Aviation Administration, followed Liying Gu's presentation with a different perspective on the same topic of civil aviation's impact on the U.S. economy. Early in her presentation, Graham discussed the importance of aviation to the economy: Civil aviation has long been the top net export for the U.S. economy, as shown in Figure 2.6(b)-1, above such commodities as petroleum refinery products, soybeans, and others. Aircraft manufacturing includes full airplanes, parts, engines, and, as of recently, avionics.

Graham referred to a Bureau of Labor Statistics website that measures how aviation affects U.S. productivity. Productivity, in economists' view, boils down to the efficiency of production, and how innovation can be measured, she explained. The FAA completed a report recently for the year 2014 that found aviation contributes $1.6 trillion in total economic activity. The report is available on the agency's website at:

(https://www.faa.gov/air_traffic/publications/media/2016-economic-impact-report_FINAL.pdf)

Aviation was found to make up 5.1 percent of the U.S. gross domestic product. It created nearly 11 million aviation-related jobs worth $447 billion.

Breaking down aviation's economic contribution into categories, nearly half is attributable to tourism, as shown in Figure 2.6(b)-2. The next largest segment is airlines, at 24 percent, followed by manufacturing at 16 percent. Manufacturing includes aircraft manufacturing, engines, parts, and avionics for both commercial and general aviation. (The 4 percent airports number, Graham pointed out, does not include governmental spending.)

Pointing out the red line in Figure 2.6(b)-3 showing growth in aviation industry output in the years between 1990 and 2014, Graham stated that output has been "growing tremendously" in the industry—to the tune of 76 percent over those years. Graham also mentioned that, in labor productivity overall, aviation ranks fourth in a Bureau of Economic Analysis/Bureau of Labor Statistics review of 63 industries. Figure 2.6(b)-4 shows the top- and bottom-ranked industries by labor productivity growth in the 1997–2014 time frame considered.

The presenter also spoke about the "KLEMS multifactor productivity" model, with the following inputs: real capital services, labor, real energy, materials, and purchased services (abbreviated as KLEMS). This broad measure of productivity, which basically measures technical change and innovation, reveals a 3.3 percent growth in air transportation over the years—three times the national productivity rate—as shown in Figure 2.6(b)-5. "One of the most impressive responses of the industry has been to oil prices" (energy portion of the KLEMS model), Graham stated. Under this multifactor productivity lens, air transportation holds the number two spot after computers and electronic products, as seen in Figure 2.6(b)-6. As reflected in Figure 2.6(b)-7 showing various sectors' contributions to the U.S. economy's multifactor productivity growth, air transportation growth was 7.3 percent, while the industry accounted for 0.3 percent of the nation's employment.

Summarizing her presentation, Graham called civil aviation a "vital engine" for U.S. economic growth. She described aviation as a high-impact small industry. Despite being 41st out of 63 industries in size, civil aviation is the:

- 7th largest contributor to overall productivity growth
- 4th highest by labor productivity growth rate; and
- 2nd highest by overall productivity growth rate.

It was pointed out that the global economic impact of U.S. aviation is much bigger than the domestic one. Another attendee brought up the workshop's focus on noise and related constraints on aviation: Any regulations that go into effect, Graham recognized, can cut into airline profits. On a related note, it was added that a recent journal article* concluded that a relatively modest, 5-decibel decrease in noise exposure could result in an annual economic benefit of about $3.9 billion.

*Swinburn TK, Hammer MS, Neitzel RL. Valuing Quiet: An Economic Assessment of U.S. Environmental Noise as a Cardiovascular Health Hazard. Am. J. Prev. Med. 2015;49(3):345-53.

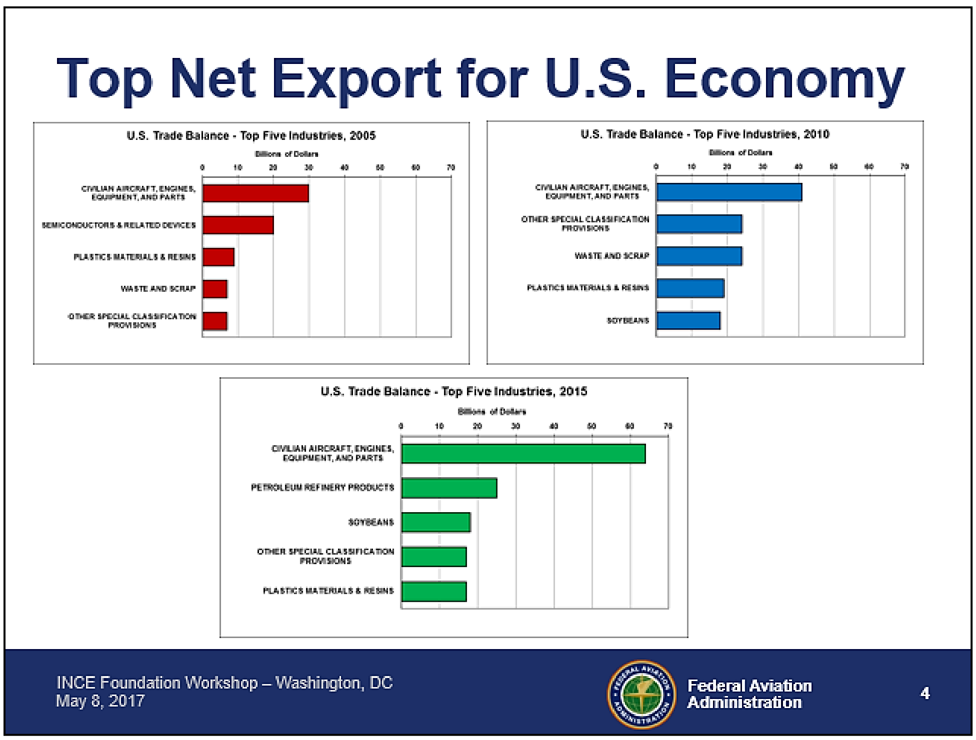


Figure 2.6(b)-1 *Aviation is Top Net Export in U.S.*

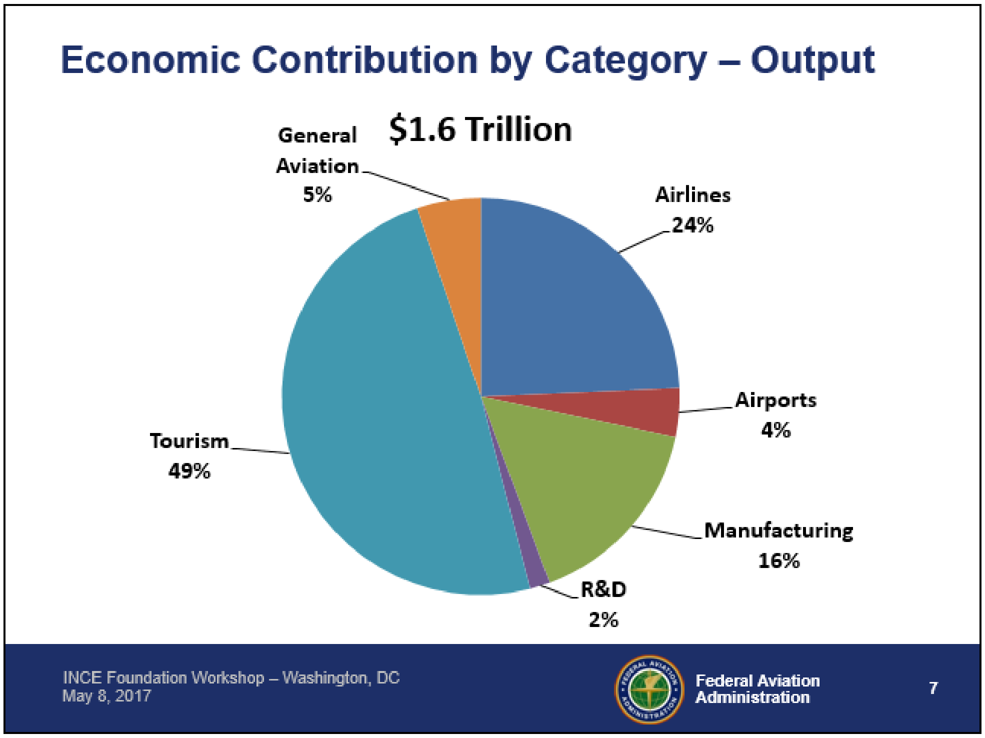


Figure 2.6(b)-2 Economic Contribution by Segment

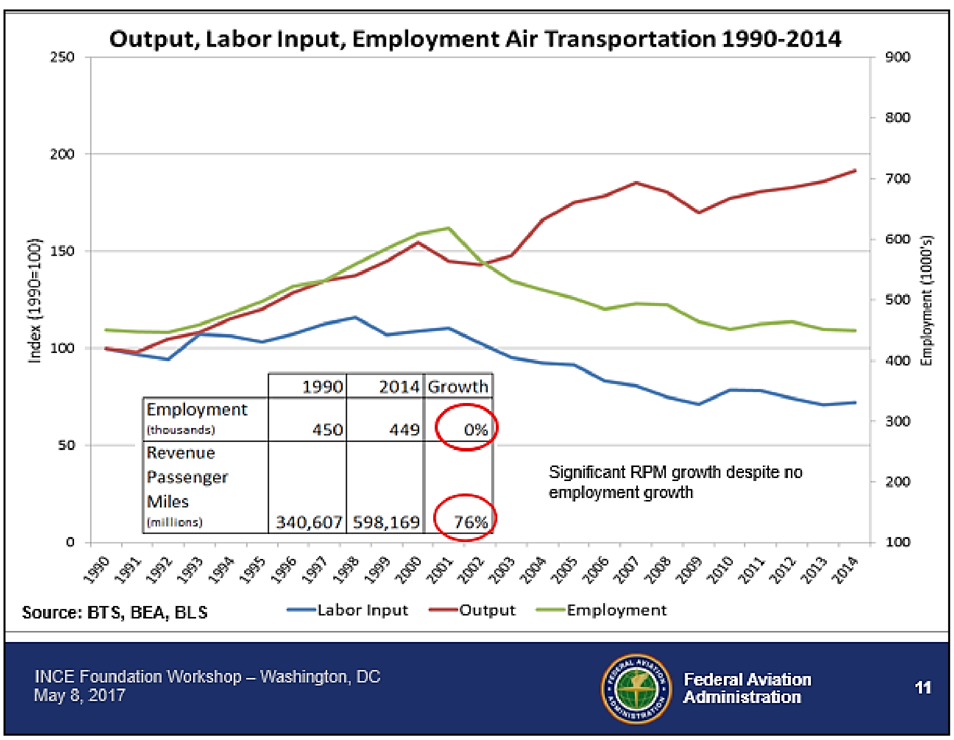


Figure 2.6(b)-3 The Aviation Industry's Rapid Growth Since 1990

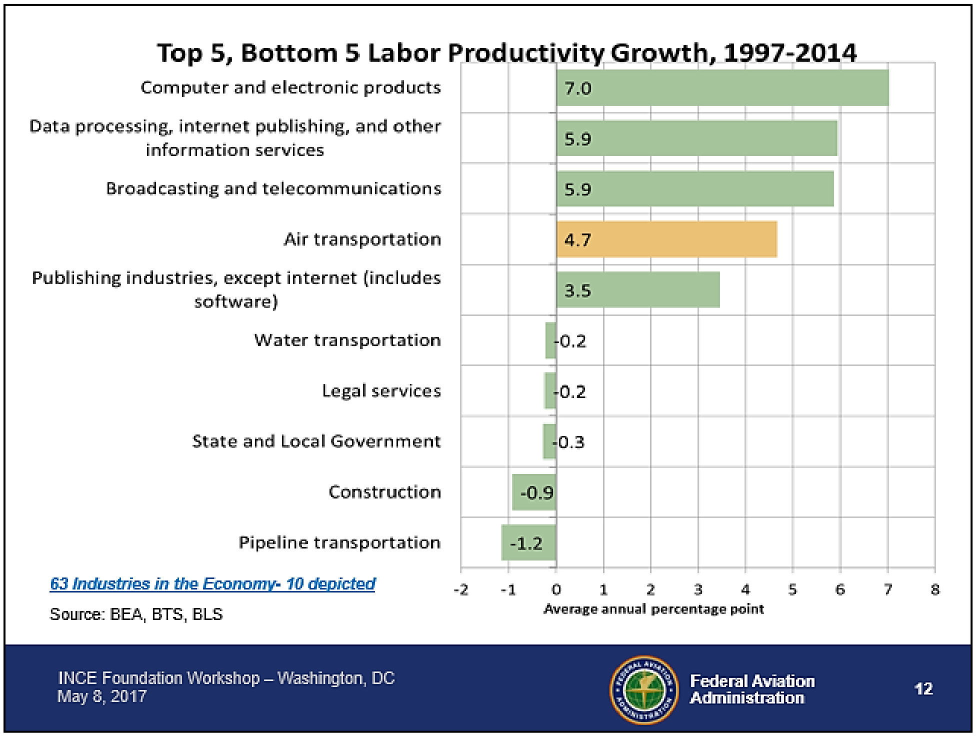
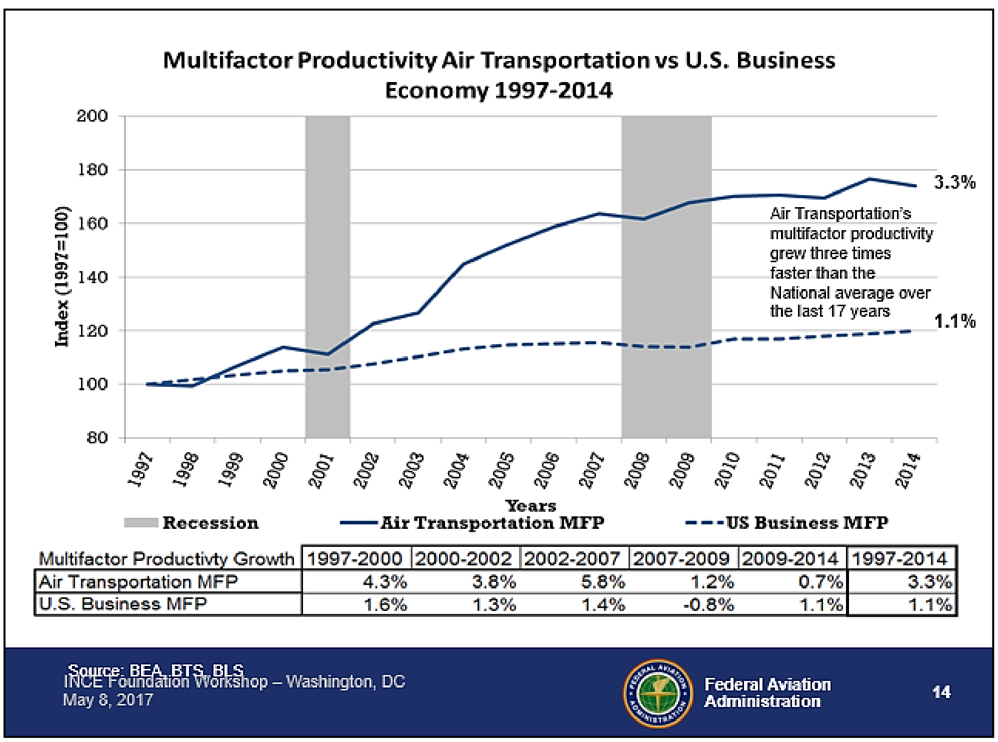


Figure 2.6(b)-4 *Air Transportation Ranks High by Labor Productivity Growth*



Multifactor Productivty Growth	1997-2000	2000-2002	2002-2007	2007-2009	2009-2014	1997-2014
Air Transportation MFP	4.3%	3.8%	5.8%	1.2%	0.7%	3.3%
U.S. Business MFP	1.6%	1.3%	1.4%	-0.8%	1.1%	1.1%

Figure 2.6(b)-5 *Another Perspective on Aviation Growth: Multifactor Productivity Model*

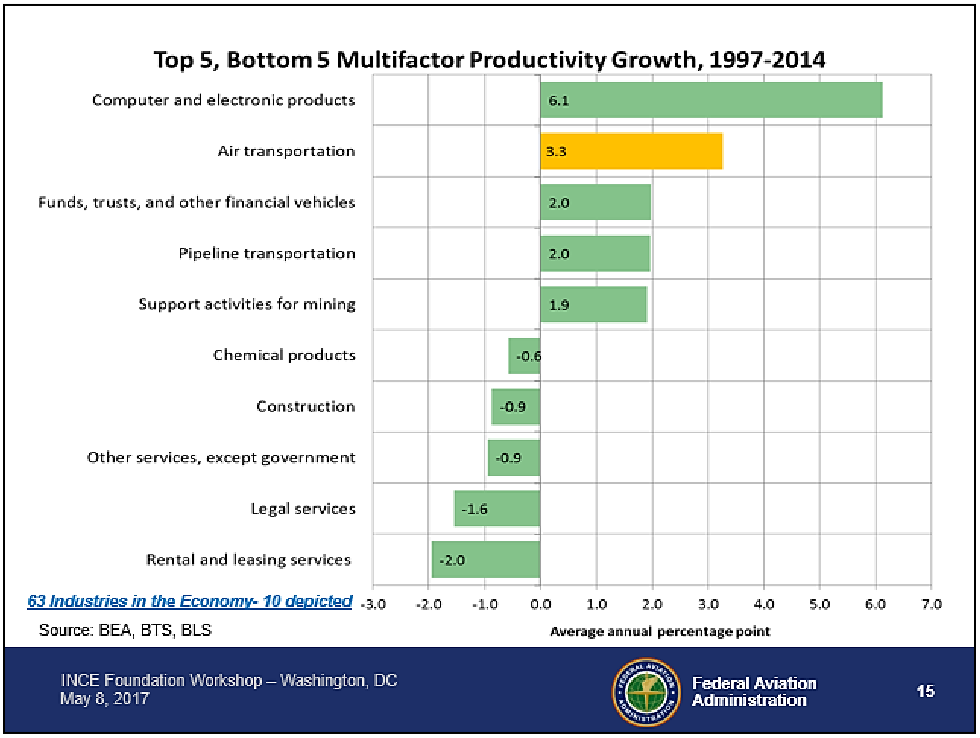


Figure 2.6(b)-6 *Air Transportation Second by Multifactor Productivity Growth*

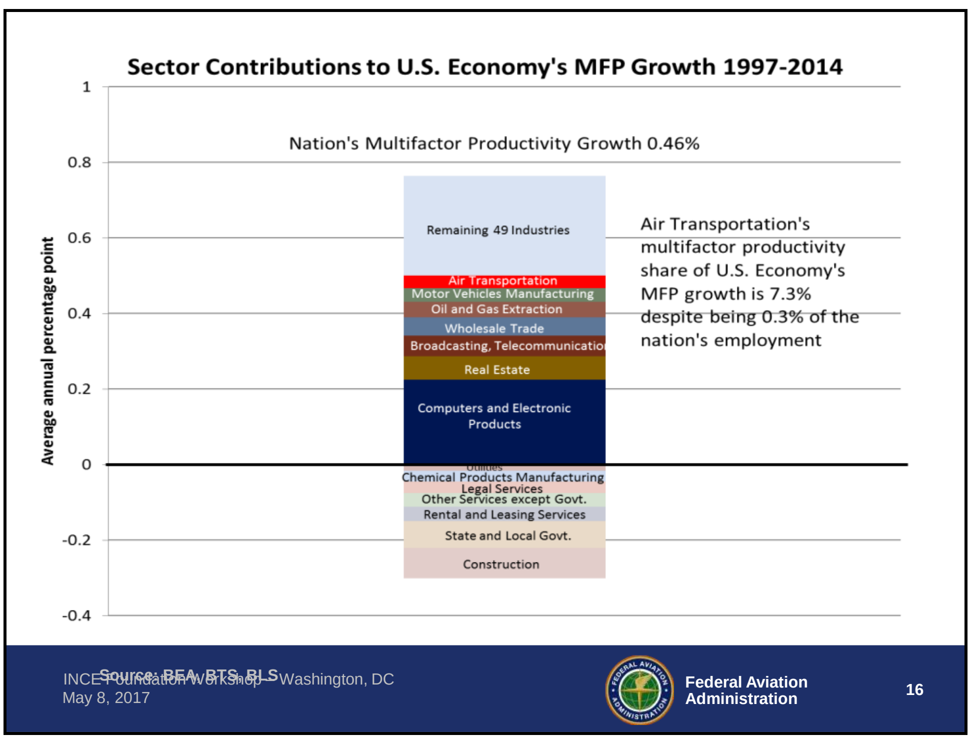


Figure 2.6(b)-7 *Air Transportation Growth: 7.3 percent*

2.7 Current Noise Constraints on Aviation and the Future with Low-Noise Technology

2.7(a) Current Noise Constraints on Aviation and the Future with Low-Noise Technology *(Presenter 1 of 4)*

Sandy Lancaster—*Dallas/Fort Worth International Airport*

Airports are challenged to control aviation noise, in keeping with responsibilities such as FAA requirements and recognition of community needs, yet aircraft operations are beyond the airports' control. Despite limited authority, airports are in a position to implement effective steps for noise monitoring and mitigation. Through education about flight data and benefits, community engagement is one measure that can address the perception of—and complaints about—noise.

Sandy Lancaster, environmental program manager at Dallas/Fort Worth International Airport (DFW) for some 25 years, began her presentation with a general description of her airport—a 24/7 operation without slot constraints or curfews, situated on 17,000-plus acres of land. This highest-capacity airport in the world has a $37 billion regional economic impact each year. Figure 2.7(a)-1 sums up this type of background information about the airport.

To support FAA-required National Environmental Policy Act (NEPA) compliance actions from its 1992 Final Environmental Impact Statement (FEIS), DFW Airport has an array of 26 noise monitors over 120 square miles around the airport. This data is match-merged with flight track data to derive an aircraft DNL for comparison to the contour. If noise exceeds the allowable level, noise mitigation measures must be taken. A challenge to airports, Lancaster pointed out, is that they are responsible and liable for aircraft noise, but do not control aircraft operations such as flight paths, schedules, and fleet mixes.

The presenter next summed up her perspective on noise management as adapted from the International Civil Aviation Organization (ICAO) "balanced approach." As shown in Figure 2.7(a)-2, Lancaster's view substitutes community engagement—which she calls "one of the most crucial aspects of all aviation noise management"—for the organization's fourth element of operational restrictions, which are not generally available to U.S. airports.

Lancaster reiterated other speakers' important message that, while noise has been reduced over time, it continues to be a "huge problem" for industry. Source noise reduction-related implications are summarized in Figure 2.7(a)-3, including the possibility of incompatible land use in the airport's environs as noise contours shrink. Noise output doesn't occur in a vacuum and people meanwhile also respond to overflights more generally, Lancaster pointed out.

The presenter spoke next about the local noise exposure forecast contours as depicted in Figure 2.7(a)-4. First created in 1971 and updated in 1992, the 65 and 75 DNL contours have been used by cities surrounding DFW Airport to guide what can be built in so-called Zones A, B, and C. Lancaster stressed, however, that while these contours are used to benchmark compatible land use in local cities, they are not acoustic contours representing today's noise status. She also pointed out that DFW Airport can only make recommendations and, while most jurisdictions have used the noise contours in their zoning ordinances, some cities have considered the shrinking acoustic contours as reason to allow incompatible development adjacent to the airport usually with some form of mitigation (e.g. sound insulation). Lancaster expressed dismay that one city approved a residential community immediately adjacent to the airport, with home values that can exceed $500,000.

After discussing DFW runway and airspace utilization and changes, including a runway rehabilitation program and runway closures, Lancaster turned the focus to community engagement. When presented with noise data based on DFW's Noise and Operations Monitoring System, people in the community were able to replace their misperceptions with factual information. The airport educates those in the community, and "people get it," Lancaster said. DFW focuses on educating people with a focus not on noise itself, but instead on how airspace works and why airplanes are flying over people's houses (because noise is the result of the overflight, it is important for the community to understand why planes fly where they do). In addition to working to inform people—with community-level demonstrations down to one-on-one education—DFW Airport works with city leaders, who are in a position to advocate on the airport's behalf in responding to complaints.

Lancaster concluded her presentation speaking about evolving noise solutions and zeroing in on the example of DFW's Runway 31L, as presented in Figure 2.7(a)-5. The airport has established an active monitoring program, for instance, using geo-fences to track departures and help ensure they occur on a precise track. This type of active monitoring has the side benefit of gaining the city's support, Lancaster said in ending her presentation.

Figure 2.7(a)-1 *Dallas/Fort Worth Airport—Facts and Figures*

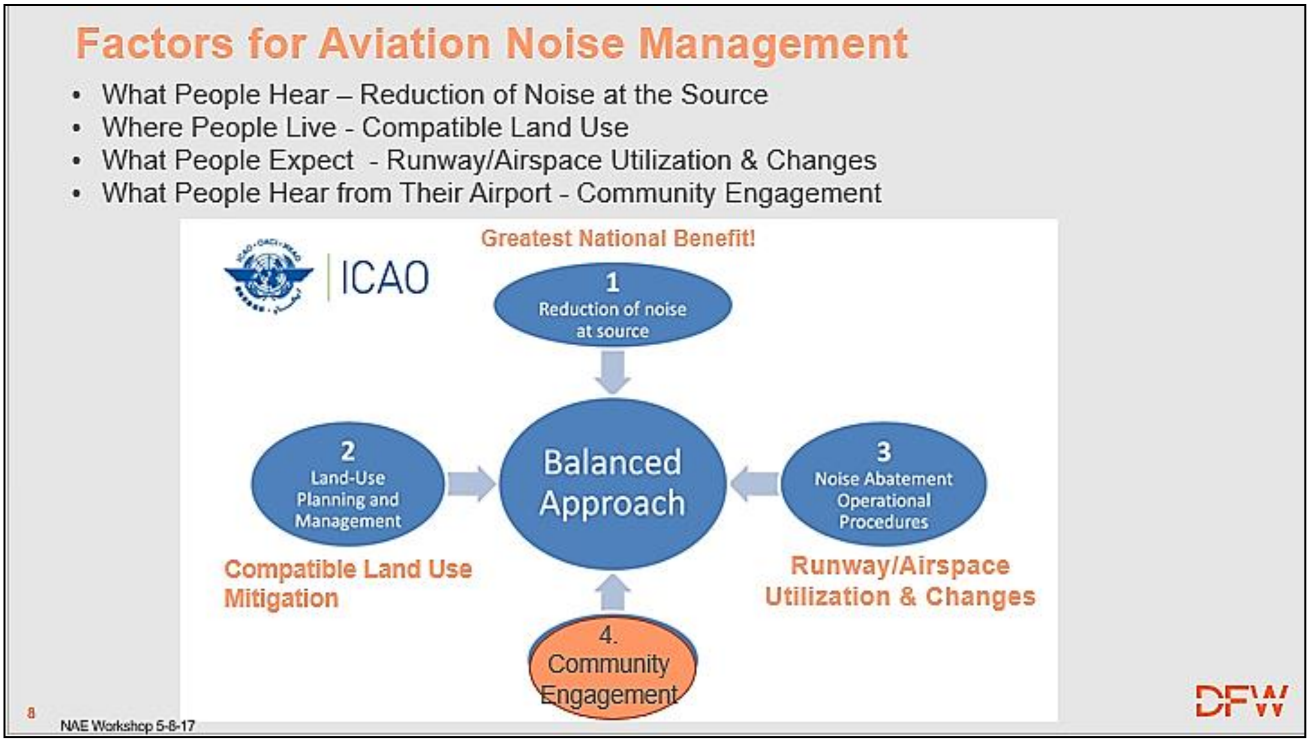


Figure 2.7(a)-2 *Balanced Approach for Managing Aviation Noise*

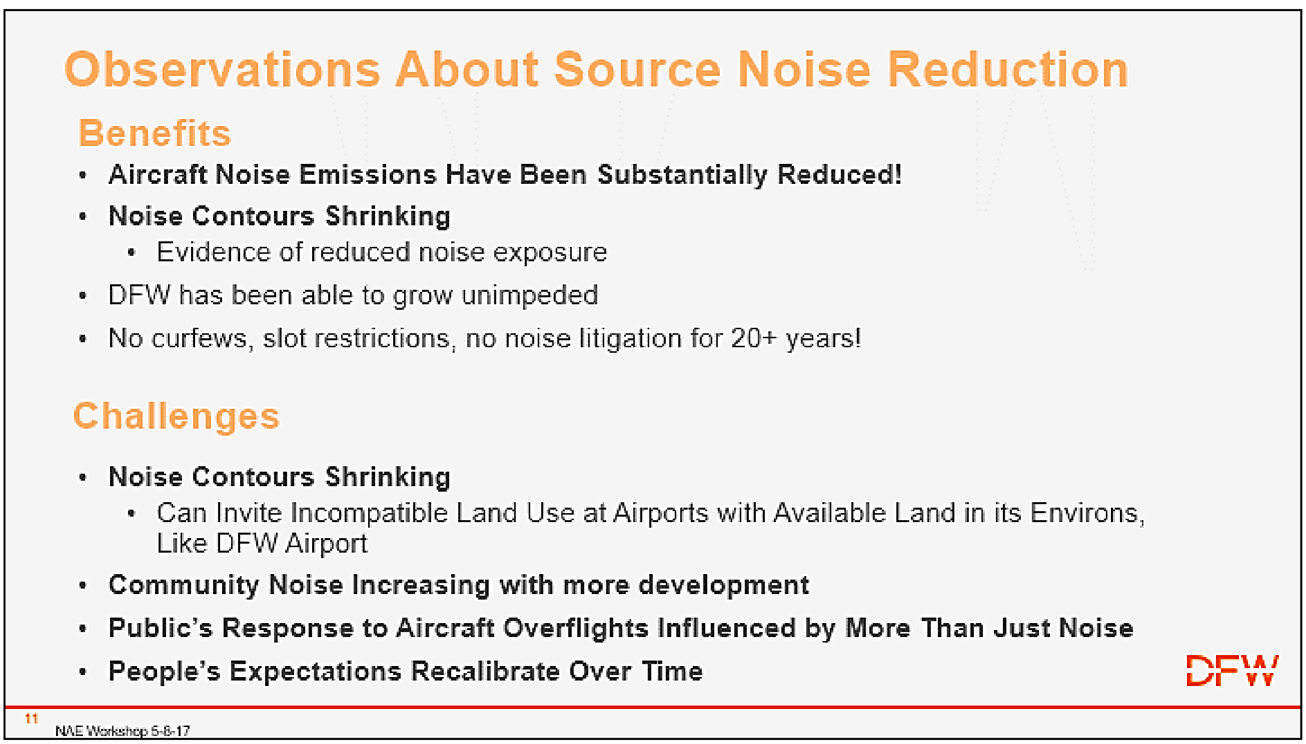


Figure 2.7(a)-3 *Noise Reduction at the Source—Observations*

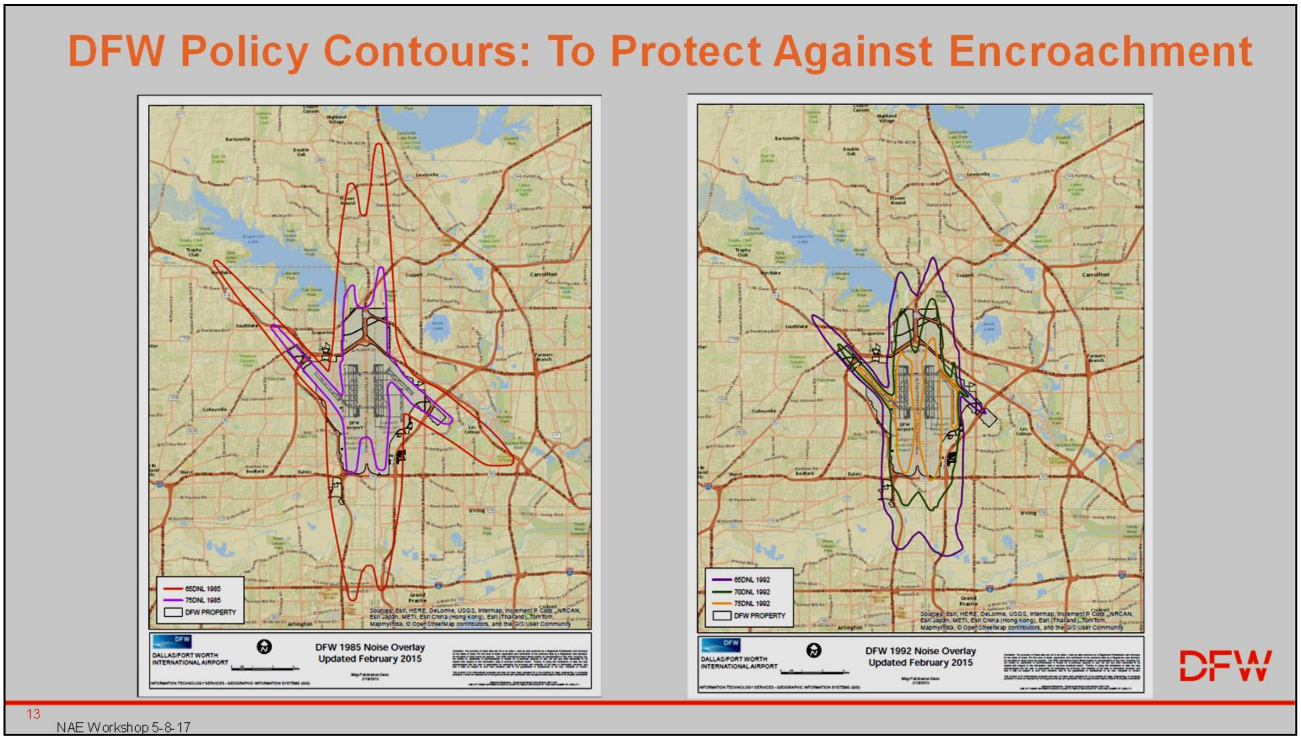


Figure 2.7(a)-4   *DFW 1985 and 1992 Noise Policy Contours*

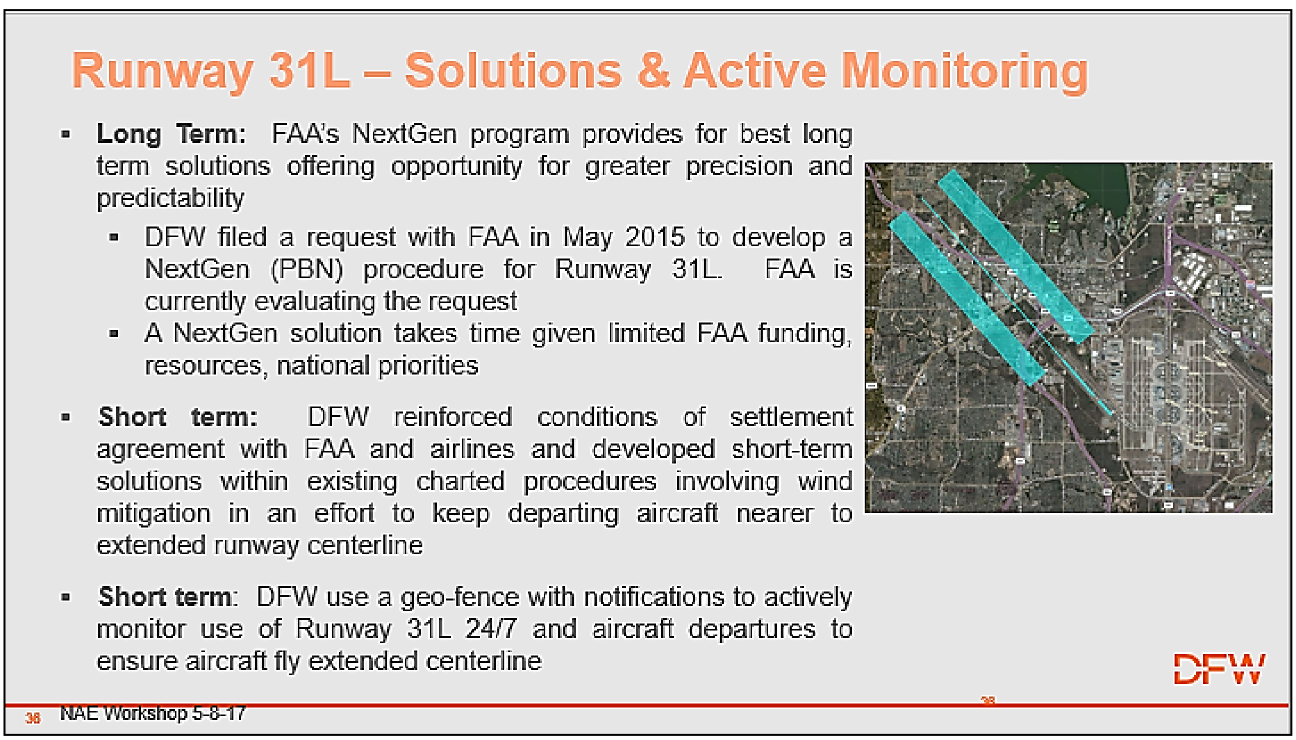


Figure 2.7(a)-5   *DFW's Emerging Noise Control Approaches*

2.7(b) Current Noise Constraints on Aviation and the Future with Low-Noise Technology *(Presenter 2 of 4)*

Flavio Leo— *Massachusetts Port Authority (Massport)*

Boston Logan International Airport has long led the way in airport noise abatement, but is nonetheless continually challenged to sufficiently address noise-related community concerns. Collaborating with government and academic experts, the airport is committed to implementing novel solutions tailored to changed flight patterns under today's Area Navigation (RNAV) method of navigation. It could take decades, not mere months or years, to fully realize the strategic vision in the works that optimally supports aviation industry growth while respecting communities' desire for quiet.

Flavio Leo, the Massachusetts Port Authority's Director of Aviation Planning and Strategy, spoke about aviation noise constraints and low-noise technologies from the perspective of airports, and specifically Boston Logan International. This urban airport has many crisscrossing runways within a small footprint, creating what Leo described as a "challenging environment" of different neighborhoods being overflown, depending on wind and weather patterns that dictate runway usage.

Logan Airport has grown to accommodate an increasing number of passengers, and has served these passengers efficiently on relatively fewer flights. Despite growing pains, Leo said, "We have a really good story to tell, as an industry and as an airport."

The airport, Leo noted, has a "long, proud history" of reducing its noise impact on the community where possible, leading the way in applying noise management tools required of a "good neighbor." New engine technology has reduced noise (on an energy basis) by more than 95 percent in recent decades, as depicted in Figure 2.7(b)-1 which contrasts a noise event from a 1980s versus a 2015 aircraft. And almost all of Logan's current fleet meets Stage 4 noise standards.

Despite the progress, the airport has seen a "huge spike" in noise complaints, which the speaker believes is largely attributable to the Area Navigation (RNAV) program under NextGen that concentrates flights into a very narrow path. Figure 2.7(b)-2 shows pre- and post-RNAV flight tracks. Given RNAV as the "new normal," Leo said, experts are now asking, "Can we do something better?"

Conversation in this regard has engaged community members, as well as representatives from the FAA, the airlines, and other experts. In collaboration with nearby MIT, a roadmap has been developed to make advances under NextGen. The technical approach, summarized in Figure 2.7(b)-3, advances the focus from radar-based approaches developed during World War II to a safety-focused, modernistic GPS-based platform. "We don't want to go back to the old radar days," the presenter stressed.

The upgrades are not without their challenges, Leo said, highlighting that "it took us decades and decades to work within the radar-based environment, so it's going to take us a while as we're going through the RNAV and GPS and Required Navigation Performance (RNP) based environment."

To address the major challenge of air traffic concentration—which the speaker said is viewed as a departure issue much more than an arrival one—the focus is on Logan's Runway 33L as a model, based on which lessons learned will be expanded to other runways. This runway's departures and overflights are shown in Figure 2.7(b)-4.

One factor being examined is why the radar-based legacy requirement of a three-mile separation between aircraft still exists, and how to deal with this constraint. A more precise platform could maintain safety, Leo said, and support more natural flight paths and "save a lot of noise for people." The potential with performance-based navigation (PBN), the speaker explained, is the opportunity to define precise noise corridors, but a challenge being examined is how to simultaneously maintain flight path flexibility. There are clearly opportunities with the PBN environment, and these are being explored at Logan, the speaker stated.

Accumulating the science base to support policies and procedures is key, though by no means a quick fix, Leo stated. The speaker concluded by posing an overarching question for consideration: Can we make the leap over the next couple of decades to provide for big environmental benefits and keep the industry growing?

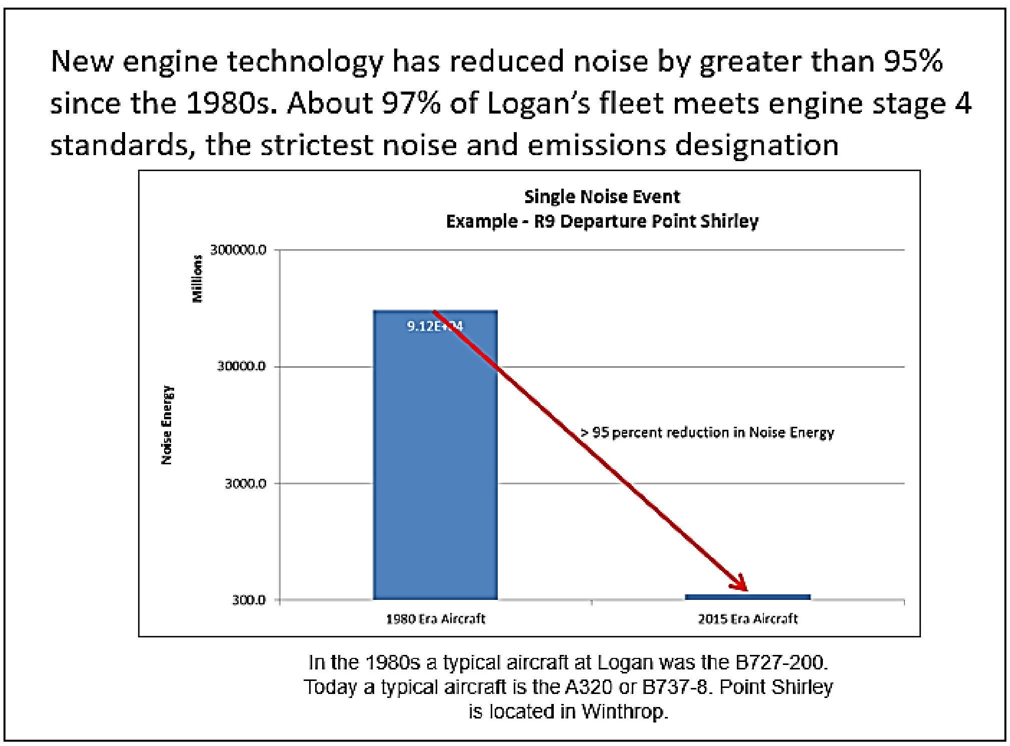


Figure 2.7(b)-1 *Newer Aircraft, Reduced Noise*

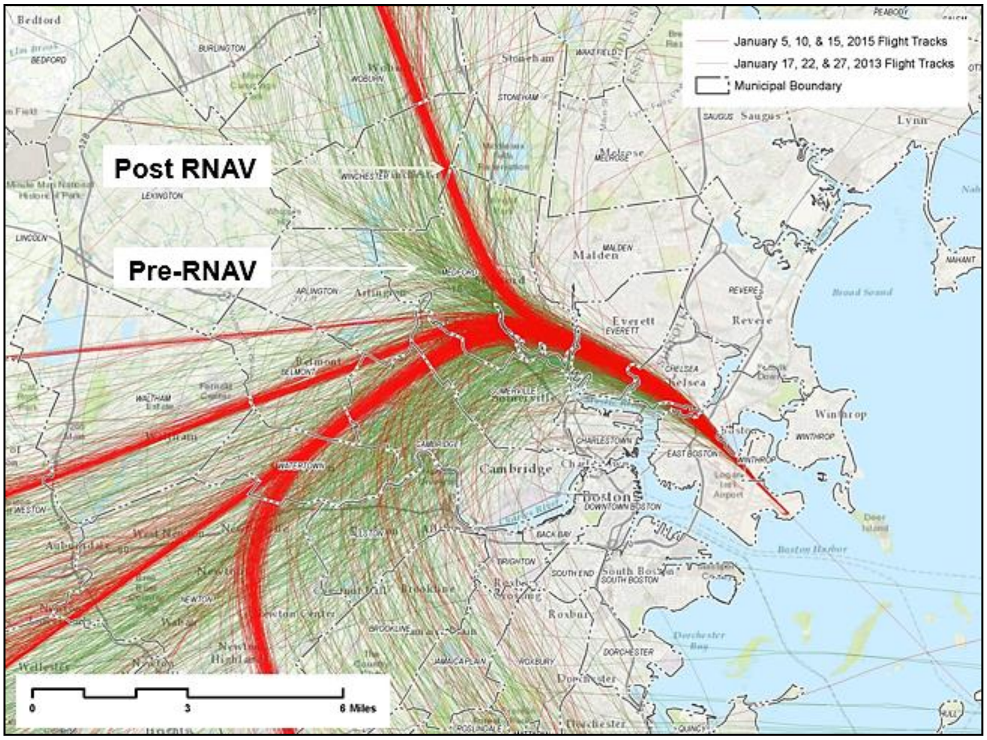


Figure 2.7(b)-2 *Flight Tracks, Before and After RNAV*

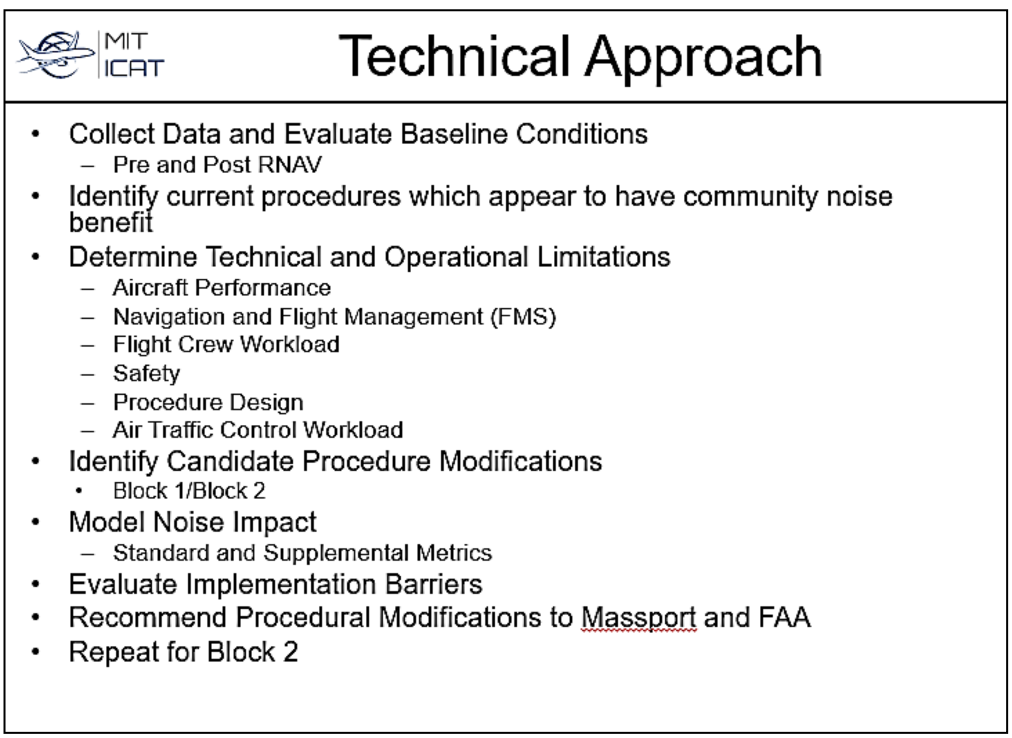


Figure 2.7(b)-3 *Roadmap Under NextGen*

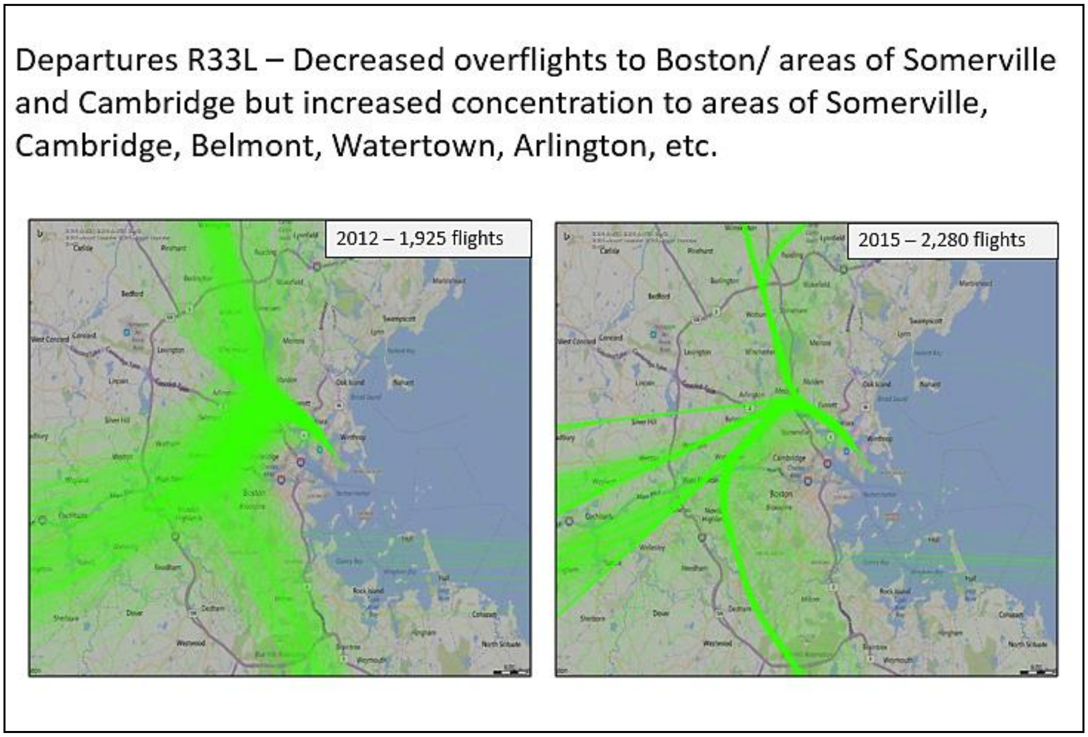


Figure 2.7(b)-4 *Revised Overflight Concentration*

2.7(c) Current Noise Constraints on Aviation and the Future with Low-Noise Technology *(Presenter 3 of 4)*

Glenn Morse—*United Airlines*

With the introduction of the innovative FAA NextGen approaches to aviation improvement have come challenges such as increased noise complaints from some residents, even as airports and airlines have increased investment and noise exposure overall has substantially declined. Along with efforts such as enhanced outreach to improve mutual understanding between communities and airports, technologies such as innovative airframes and engines are sure to play a big part in addressing noise burdens. To win industry acceptance, however, any proposed technology upgrade must survive a cost-benefit test.

Glenn Morse, United Airlines' Director of Industry Affairs, spoke from the airline perspective about aviation noise challenges, associated noise management technologies, and barriers to technology development and implementation. By way of background, Morse characterized the Boston-New York region as the East Coast "nucleus" of noise abatement efforts over the last 40-plus years. Attitudes are far different, he highlighted, since the FAA's dismissive "don't worry, you'll get used to it" response some 30 years ago to citizens complaining about aviation noise above their homes.

Despite tremendous investment by United Airlines and others, and significant reductions in community residents' noise exposure, as reflected in Figure 2.7(c)-1, the industry is still left asking, in the face of rising noise complaints, "Where did we go wrong?" and, more specifically, "How did we go off track with RNAV (Area Navigation) approaches?" NextGen and PBN (Performance-Based Navigation), in particular, have been a double-edged sword, by Morse's characterization, having created their own challenges and meanwhile "spawned a new era of community outreach and collaboration."

Morse credited a combination of factors for lingering noise issues, some of them listed in Figure 2.7(c)-2. Among them: the NextGen Metroplex projects, designed to enhance aircraft navigation in metropolitan areas with multiple airports and driven in large part, according to the speaker, by the cost of fuel, but with the ancillary benefit of reduced emissions. Another contributor is new close-in PBN procedures, like the "notorious" LaGuardia Runway 13 TNNIS (straight out) departure and others that were facilitated by the Legislative Categorical Exclusion (CatEx), Section 213 of the 2012 FAA Reauthorization.

Returning to a focus on RNAV and its shortcomings, Morse addressed the influence of social media, which allows instant communication among noise constituents from the East to West Coast and everywhere in between. After briefly mentioning the Congressional Quiet Skies Caucus, whose member count has reached about 40, and the four Federal Aviation Regulations Part 150 studies being undertaken in New York, Morse mentioned that RNAV procedures can change where airplanes fly, even when they are developed as apparent "overlays" of existing procedures. The speaker gave the example of the Washington, DC, river approach that lands on runway 19.

The new emphasis on collaboration and community outreach is exemplified by stepped-up efforts such as these: updated FAA community engagement programs and best practices, as recommended by the Radio Technical Commission for Aeronautics (RTCA) NextGen Advisory Committee; an updated FAA community outreach manual; PBN-focused Airport Cooperative Research Program (ACRP) projects focusing on PBN and community outreach by airports; FAA-recommended airport roundtables, including ones in New York and New Jersey; and enhanced outreach on airspace projects.

Community outreach efforts aside, controlling noise at the source must be seen as a primary goal, Morse emphasized. Figures 2.7(c)-3 and 2.7(c)-4 list some primary hurdles in developing and implementing technological solutions. “Obviously, new engine and airframe technology will be a significant piece of the puzzle,” the presenter stated, adding that he was impressed with the blended wing aircraft discussed earlier in the workshop. As with previous aircraft entering the fleet, questions remain—involving dimensions such as wingspan and gate footprint, for example, and how these factors translate into airport investment to accommodate the aircraft. Carriers, too, are concerned with balancing the costs and benefits associated with any new technologies.

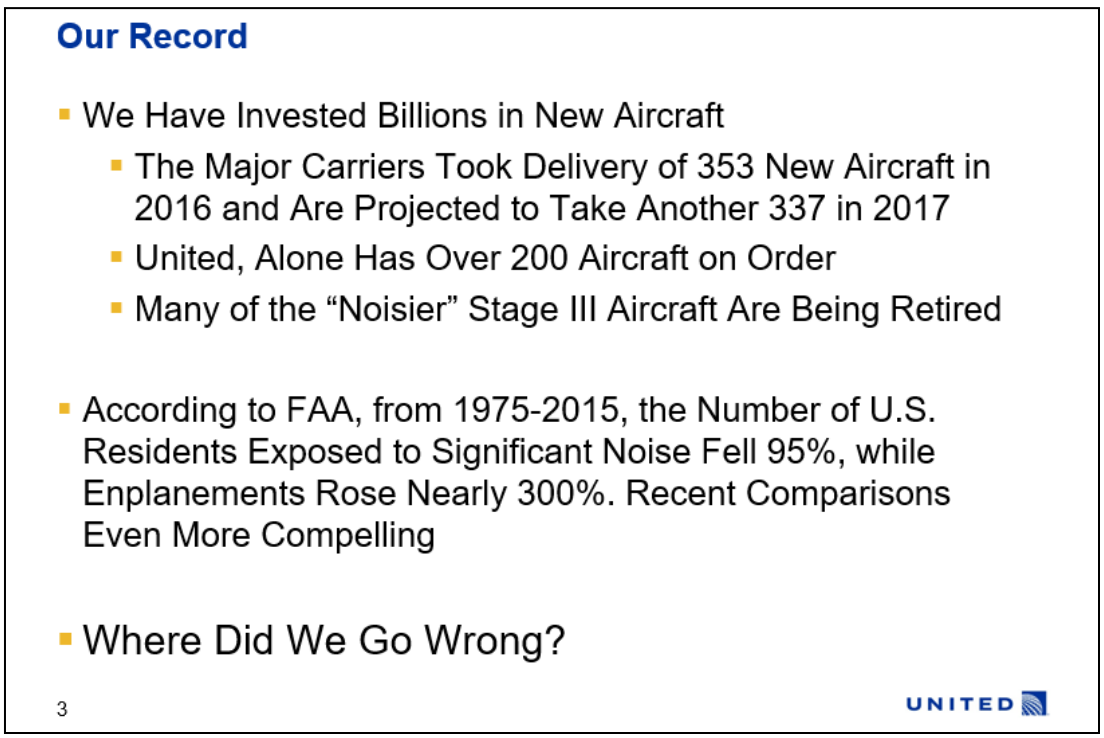


Figure 2.7(c)-1 *Increased Investment, Reduced Noise*

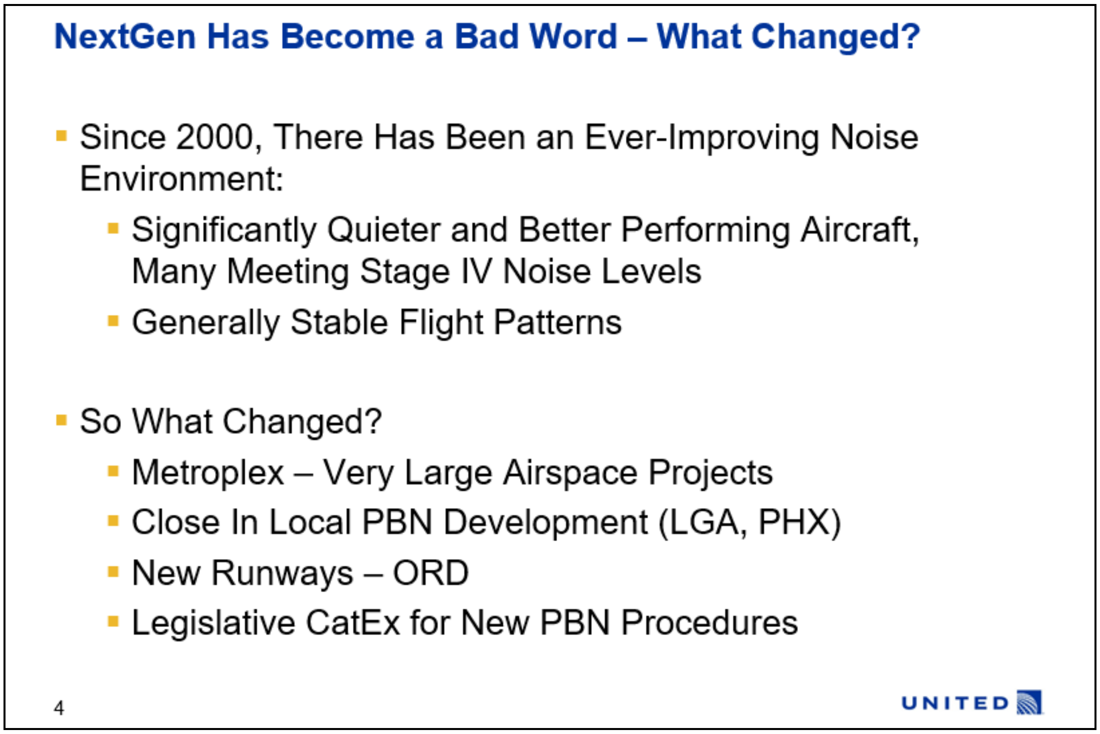


Figure 2.7(c)-2 *With NextGen Innovations Come Challenges for Some*

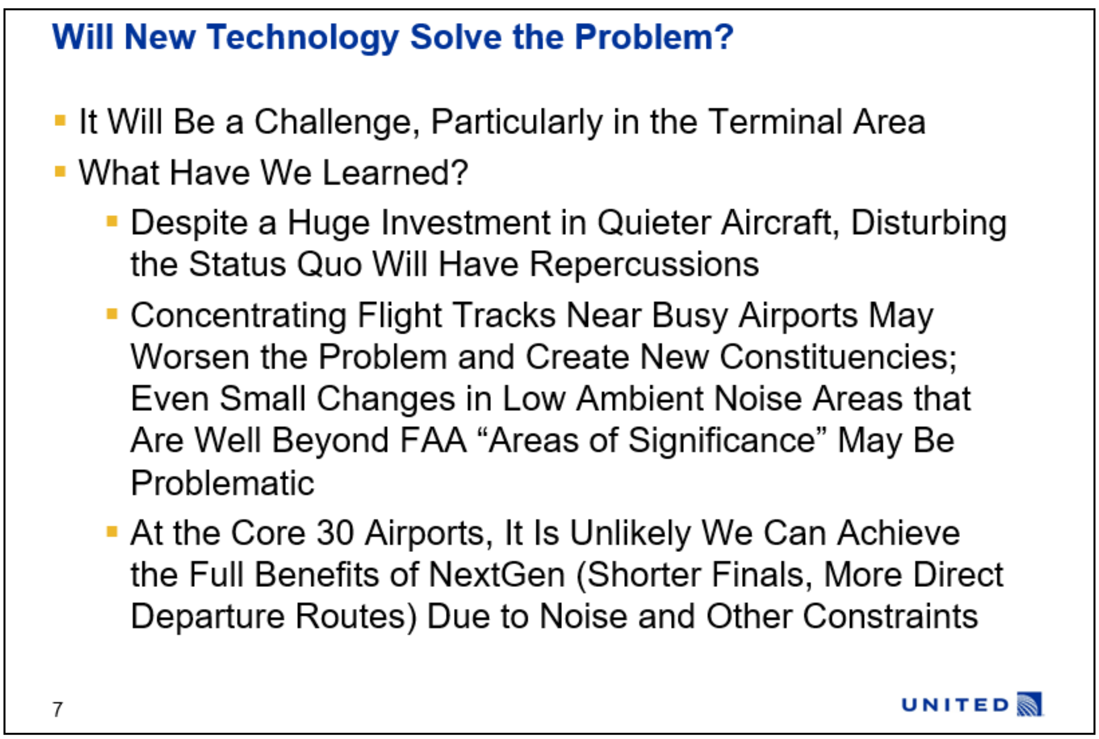


Figure 2.7(c)-3 *Technology's Challenges: Lessons Learned*

Will New Technology Solve the Problem?

- New Engine and Airframe Technology Will Be a Piece of the Puzzle, But Will Not Guarantee Unfettered Access to the Airspace, Particularly if It Introduces New Noise and Over Flights
- Arrival Noise Is a Growing Concern: Few Opportunities to Vary the Flight Path; and “Shorter Finals” May Not Be Feasible in Congested Urban Areas, Unless Unique Geography or Land Use Supports New Flight Tracks
- Noise Is Often a Surrogate for Other Issues
- The True Impacts of Noise “Restrictions” on Airport and Airspace Capacity and Flight Efficiency Need to Be Quantified and Validated (e.g. BOS, LAX)

8

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Figure 2.7(c)-4 *Technology as Solution: Concerns Remain*

2.7(d) Current Noise Constraints on Aviation and the Future with Low-Noise Technology *(Presenter 4 of 4)*

Stephen Alterman—*Cargo Airline Association*

Even if not solvable in an absolute sense, aviation noise issues—which are applicable to the cargo airline industry as they are to passenger airlines—can be managed by a variety of approaches not limited to technological improvements. And, while cargo airlines face some distinct challenges, the airline industry overall can take helpful steps even as technology is being developed. Educating those in the community affected by aircraft noise is crucial, and leveraging opportunities for government-industry collaboration is likewise a valuable course of action.

Cargo Airline Association President Stephen Alterman added his perspective on select points that previous workshop presenters had raised relating to noise constraints and low-noise design technology. The speaker (who presented without slides) opened by stating that technology cannot solve aviation noise-associated challenges. "We're not going to solve the problem," said Alterman, "because airplanes fly over people's heads and they make some amount of noise, period." The problem can be managed, however, Alterman said, and the question is how to manage it.

Routes may change and systems may be modernized, but changing patterns simply mean that airplanes are flying over different people's heads, Alterman stressed. Having recognized this issue, he said, the FAA has conducted noise surveys and other research to better understand the effects of aviation noise on the community. Industry and FAA communication with those affected, based on this information, could go far in helping people understand noise issues associated with modern aviation.

Alterman next presented some background on the Cargo Airline Association which is made up of airlines such as FedEx, UPS, Atlas, and DHL that only carry freight. Despite their different business models, cargo and passenger airlines are "all in this together" in terms of dealing with noise challenges, he said.

The cargo industry has certain unique problems. A much larger percentage of their flights are at night, Alterman said (also pointing out that two-thirds of night flights carry passengers, not cargo, however). Daily utilization and revenue is lower for cargo airplanes than for passenger airplanes. Commonly—though less so than in the past—cargo airplanes are used aircraft, and often they are passenger planes converted into cargo configurations. This means that quieter aircraft are not introduced as often in the cargo fleet as in the passenger fleet.

Also, curfews can uniquely impact cargo airlines because of their service guarantees. "We're selling guaranteed delivery from point A to point B within a definite time," the presenter said. And, mainly due to a pilot shortage, freight is increasingly delivered by truck rather than by air, according to Alterman. (Nonetheless, the cargo airline industry at times must add planes to its fleet, the presenter stressed, with new members—most recently, Amazon—coming on board.)

Next, Alterman highlighted the tremendous influence of politics on the industry, and also the importance of industry-government collaborations such as the CLEEN program. It is important to leverage successes in these types of programs that spur the contribution of federal and private funding alike. "I think when everyone has a stake in the program—when the industry is investing with government, and not just taking from government—things can get done," Alterman stated, adding that both sides must be willing to put up development dollars. Alterman also pointed out that NASA and FAA are "teammates" today, whereas in the past they were at odds.

The cargo airline industry, like the passenger one, is challenged by the notion of the aircraft of the future and how to modernize in light of current business models: What does the airplane of the future look like? And how can it be made quieter? (Some advances in the works are uniquely suited to cargo operations, Alterman pointed out, such as the windowless blended wing aircraft.)

New aircraft, and new technology, create problems even as they present solutions, Alterman said. And ordering new aircraft is by no means a short-term solution. "When you order them, you don't get them tomorrow." Meanwhile, what can be done? Understanding community objections is a start, Alterman said. Characterizing aircraft noise as "a very, very tough problem," the presenter stated, "That's why sessions like this are important." In conclusion, Alterman said, "The reality is, we have to try to manage this problem at the community level, the airport level, and the airline level, while we develop the things that need to be developed for the new technology."

In response to an audience question "Would your industry be stronger with quieter airplanes?" Alterman said "the answer is complicated." Pointing to the issue previously raised about curfews, the presenter said that not many have been imposed on planes in the United States, although the possibility exists and quieter airplanes could put this issue to rest. The presenter raised the issue of the economic perspective on less noisy planes, which typically translate into less fuel consumption. "One of the reasons we would like quieter planes is they're more efficient, and so our operations become more efficient, and they become economically more justified."

Noise is not a problem to consider in isolation, the cargo airline representative said, as it can go hand-in-hand with economic implications. "The fact is, sometimes solving noise issues hurts emissions issues," Alterman stated, "and it's a very difficult dynamic." In summary, he said that, by helping to address these types of hurdles, modernization and new technologies can play a role in reducing both noise and emissions and at the same time make economic sense.

Figure 2.7(d)-1 *Several CAA Member Photographs from CAA Website (post-workshop)*

2.8 Panel Discussion—Day 1: Opportunities With a Low-Noise Future

Panel Moderator: Megan Knight, N.O.I.S.E. (National Association to Insure a Sound Controlled Environment)

What will it take for the aviation community to invest in, and bring to fruition, a low-noise future for aviation? The answers are complex, according to workshop attendees, and require both public and private parties to appreciate the advantages. Businesses are motivated by monetary incentives. Revised metrics could play an important supporting role by further clarifying noise effects on communities.

During this Day 1 panel, which was moderated by Megan Knight representing the N.O.I.S.E. organization, panelists and other attendees discussed opportunities for realizing a reduced-noise era in aviation. One issue presented for discussion was the types of technology improvements necessary for the aviation community to sign on to design and operate new aircraft.

The United States will benefit from research, design, and manufacturing funds invested toward low-noise airplanes, commented an attendee. He stressed that China recently announced its commitment to become a significant competitor in the global commercial aircraft market, and that the U.S. government and manufacturers must focus on maintaining U.S. dominance in commercial aviation while supporting the design, development, and commercial introduction of significantly quieter aircraft.

The question was posed, could low-noise airplanes receive special privileges like cars do in high occupancy vehicle (HOV) lanes, to spur investment and innovation? Such "HOV-type" opportunities could become available, given the accuracy of today's trajectory-based navigation systems, but congested airspace and differences in how aircraft are equipped raise challenges of segregating this way. On the other hand, accommodating various flight paths would be made easier given that quieter aircraft could lessen flight constraints based on today's noise abatement patterns. An attendee raised the possibility of "HOV times," instead of distinct flight patterns, which would allow significantly quieter airplanes advantages in terms of flight time flexibility.

With a step change to significantly quieter aircraft could come the possibility of flying in and out of airports the world over with greatly reduced restrictions. Such improved flexibility could ultimately improve airlines' bottom lines—for example, by helping international packages reach their destinations on time without being impeded by curfews and other such restrictions. Fewer flight restrictions on quieter aircraft would be a "major benefit" to carriers.

Current designs are at least approaching their potential, a workshop participant said, opining that heavy investment in new aircraft designs is needed—and promptly, given the time it will take to penetrate the market. Someone raised the possibility of replacing single limit values with two limit values for aviation noise, to more easily distinguish severe discrepancies from minor ones.

A discussion followed about China's investment in aviation. It was stated, "Last year, China committed the equivalent of $15 billion for the next 20 years, to invest in propulsion technology alone." That investment by China far exceeds current investments in the U.S. on an annual basis. Even funds for the CLEEN program have been threatened in Congress, an attendee pointed out. It was stated that the CLEEN program, and similar programs, in fact exemplify efforts worthy of investment together with government funding coupled with private investment.

Returning to the topic of aircraft design itself, attendees discussed that future airplane designs might present barriers for airports and carriers that would need to accommodate the new airplanes within their infrastructure. Consideration should be given to what a real transition would require to incorporate state-of-the-art vehicles and propulsion systems.

It was noted that, given real business opportunities, carriers would go to airplane and engine manufacturers and define what they need. Again, the importance was raised of manufacturers working jointly with the federal government.

Airports should be involved early in aircraft development discussions, said an attendee, to help ensure that new aircraft can blend into the system by flying the same routes as other planes and can realistically be accommodated. Air traffic rules must be considered, as well.

An attendee stated that large changes in aviation to reduce noise levels would have to come in the form of a top-down push from both government and industry. Top aviation industry leaders and federal government policy makers must work together, he said. Still, an attendee stressed, benefits must be monetized: It is the profitability of the industry in recent years, and the efficiencies of new aircraft, that has drawn investment in fleet renewal. Noise benefits are seen as a significant side benefit. So how can investments in quieter aircraft be monetized? Possibilities mentioned included reduced air navigation service provider charges or other types of incentives from airports and the government.

Metrics related to area navigation (RNAV) and required navigation performance (RNP) routes and associated noise and annoyance were discussed next. Spreading the noise level across a wider area by making routes “less precise” is being explored to reduce community impacts, according to an attendee. While adjusting flight paths according to more sophisticated analyses promises to provide meaningful noise relief, safety factors must of course remain paramount when proposing sometimes-complex adjustments to the flight environment.

Metrics that consider factors related to annoyance that are not limited strictly to noise levels may come into play. Workshop participants discussed the challenges with a subjective noise metric based on public annoyance. Whether exposing more people to more moderate noise is preferable to exposing a few people to more noise reaches beyond metrics and becomes a philosophical, political, and ethical question.

It was suggested that creative low-noise flight procedures could be developed with the aim of implementing them during periods of low traffic, such as at night. A workshop participant stressed that problems can arise if procedures are developed that are not applicable from a national perspective but only apply to specific airports.

A workshop attendee highlighted the importance of communities and industry reaching a realistic middle ground when it comes to examining community impacts, rather than residents exaggerating the effects on them and industry downplaying these effects. Speaking to the subjective nature of complaints, an attendee mentioned that different people experience and report the noise in various ways, and sometimes noise can be misperceived based on several factors. (A larger aircraft can optically appear to be closer relative to a smaller aircraft, for example.) Complaints can in some cases represent useful feedback, the participant said, but mostly community engagement focuses on helping people understand the realities of where they live in the context of flight noise.

Someone asked whether amended sound measurement methodologies could more accurately capture the reasons for people’s responses to noise. Would measuring sound quality, in addition to noise levels, provide helpful clues? Attendees said yes, and may be possible to learn from current literature and additional research how to change noise components to disturb people less. Then, the question becomes whether and how theoretical lessons learned can be integrated into actual changes to aircraft design.

3

AVIATION LEADERSHIP, ECONOMY AND SECURITY

3.1 Keynote Speech: Maintaining America's Leadership in Aviation

Carl Burleson—*FAA*

Aviation is vital to the American economy, but noise remains a key constraint on the industry's growth. The FAA is committed to developing solutions for noise and other environmental challenges to ensure that aviation continues to thrive. To that end, the agency is conducting rigorous research to understand community concerns and other relevant factors, and any FAA regulatory policy will only be adopted after public input is invited and thoroughly considered. Meanwhile, noise challenges are emerging associated with helicopters, unmanned aerial systems, and civil supersonic aircraft.

Carl Burleson, the FAA's Deputy Assistant Administrator for Policy, International Affairs, and Environment, opened the second day of the Commercial Aviation "Quieter America" workshop as keynote speaker, presenting an overview of U.S. aviation and the challenges it faces. As predicted based on research conducted more than 10 years ago by the FAA in collaboration with its PARTNER Center of Excellence, Burleson said, aircraft noise has become the key constraint on aviation growth based on its effects on communities.

First, the good news, he said: "Aviation is a vital part of economic growth in America," as shown in Figure 3.1-1. It is in America's best interest, then, that noise—along with other environmental challenges in the areas of air quality, climate, and energy—are solved in support of continued robust growth, he said.

Burleson next discussed the environmental and energy goals in support of increased mobility, as summarized in Figure 3.1-2. While people do not generally associate NextGen with environmental factors, these have integrally shaped the system and its implementation, Burleson said. The FAA's environmental protection vision and principles focus on allowing aviation to thrive while limiting environmental impacts to protect the public health and welfare, and meanwhile ensuring energy availability and sustainability.

Burleson said the FAA laid out its vision of allowing environmental protection and sustained growth using the principles shown in Figure 3.1-3. The FAA's multi-solution approach toward achieving its aviation goals is presented in Figure 3.1-4 in terms of several pillars:

- *Science and Tools.* In collaboration with other experts, the FAA has developed a sophisticated set of models that integrates noise and emissions information.

- *Technology.* The FAA's Continuous Low Energy, Emission and Noise program (CLEEN) exemplifies the agency's efforts to accelerate incorporation of new noise and emissions technologies into aircraft. The program is viewed as a model for technological innovation, and leverages tax money by attracting complementary industry investment.
- *Alternative Fuels.* In collaboration with industry, the FAA created a "tremendously successful" commercial aviation alternative fuel initiative (CAAFI) and, as a result, alternative fuels are beginning to be adopted into aircraft. Much more progress must be made, but these fuels are moving toward commercial viability, Burleson said.
- *Operations.* Planning and implementing operational procedures to minimize noise has been among the FAA's top priorities recently. Noise is increasingly considered in the air traffic context, and new positions are being created specifically for community engagement.

Figure 3.1-5 addresses the challenges ahead: Although there are beneficial impacts of modern advances in aviation noise, there are also the unfortunate increases in associated community concerns. NextGen has sometimes become "shorthand" for noise impacts even when the program is entirely unrelated to changes in noise exposure, Burleson said. "Part of the challenge going forward is to recognize that we cannot rest." Quantifiable past successes in noise reduction are insufficient if communities are unhappy with the current reality. As shown in Figure 3.1-5, increased frequency of quieter operations, concentration of operations under performance-based navigation (PBN), and flights in new locations are among the issues that are causing negative community reaction. And opposition has occurred even at substantially lowered day night noise levels (DNL) compared to the traditionally significant 65 DNL—not always based only on just the quantitative sound level, but sometimes also due to other, social and psychological factors. Meanwhile, the FAA cannot control certain aspects of the system.

Burleson next explained what the FAA is doing to address these challenges, as presented in Figure 3.1-6. The FAA has been conducting a study in communities across the country to look at what noise policy should be proposed in light of modern circumstances. Before adopting any policy, Burleson assured, the agency will initiate a notice and comment process to solicit public input. This process could begin by early 2018, and so adoption of a policy would not be expected to occur until late 2018, Burleson predicted.

Figure 3.1-7 shows the FAA's specific near-term goals in terms of new technology to reduce noise, as well as reduce fuel consumption. The CLEEN program, undertaken in partnership with Pratt & Whitney, is enabling a cumulative noise reduction of 25 EPNdB, along with a fuel consumption reduction of 20 percent. The figure also shows longer-term concepts that the FAA is helping to develop. The CLEEN Program represents a model of technological innovation, Burleson said, and boasts wide support from federal government agencies and on Capitol Hill. At least in part, he said, this may be attributable to its approach that leverages tax dollars with matching funds from industry which, in tight budgetary times, is an effective way of accelerating new technologies.

The speaker next mentioned helicopter noise, which has changed from a "non-issue" into a lightning rod in certain locations across the country. On both the modeling and operations sides, the speaker said progress is needed toward newer technologies for quieter helicopters.

Next, Burleson spoke about unmanned aerial systems (UAS), commonly referred to as drones, which he said have been the subject of the great majority of recent news stories relevant to the FAA's work. Beyond the safety component that is an FAA focus, related issues include privacy and national security. And how will the FAA deal with UAS noise? "I think we're going to have lots of challenges" in this area, said Burleson.

Burleson next discussed civil supersonic aircraft noise. Industry is interested in returning to civil supersonic flight, which has been prohibited over land since 1973, and manufacturers have vocalized this interest to the FAA and Congress. The FAA is conducting research in this area, in collaboration with industry, NASA, and ICAO. Among the goals: creating a lower-boom aircraft, assessing and modeling impacts on communities, and developing en-route noise certification standards. But challenges remain. For example, as Stage 5 noise certification standards may be around the corner, some current supersonic configurations fall short of even Stage 4.

Burleson concluded his presentation on an optimistic note, calling recent aviation advances an extraordinary success story. Still, environment and energy constraints remain significant as summarized in Figure 3.1-8. Noise issues, in particular, are shaping the implementation of NextGen technologies and procedures. Engagement with communities and partnerships with various stakeholders will be key to developing safe, efficient aviation approaches that also help minimize noise concerns. Burleson concluded, addressing workshop attendees about continuing to reduce noise impacts: "I think we have a striking challenge before us, and we in the FAA look forward to working with you to meet it."

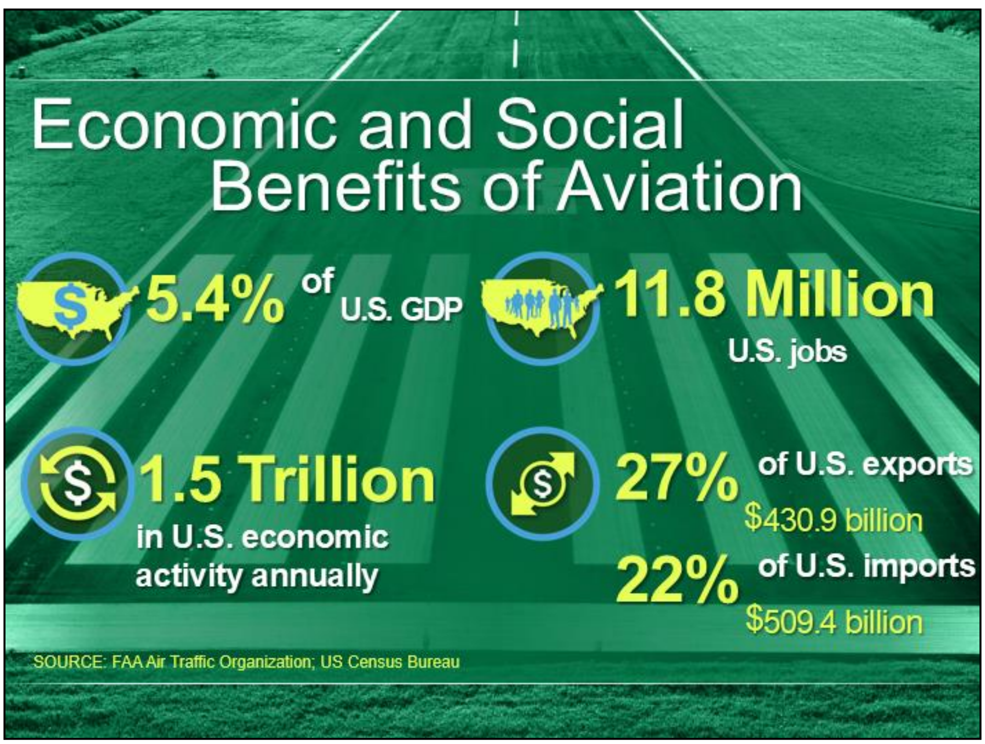

Figure 3.1-1 *U.S. Aviation's Benefits*

Figure 3.1-2 *Environment and Energy Goals in Support of Aviation*

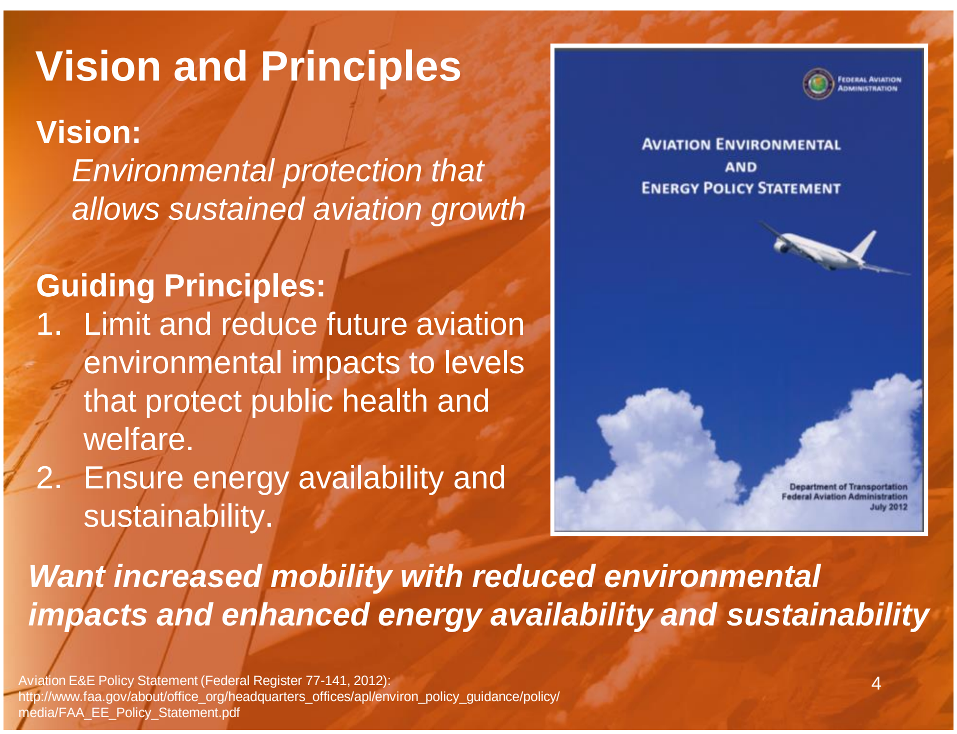

Figure 3.1-3 *Vision and Guiding Principles*

Figure 3.1-4 *FAA's Five Factors for Aviation Solutions*

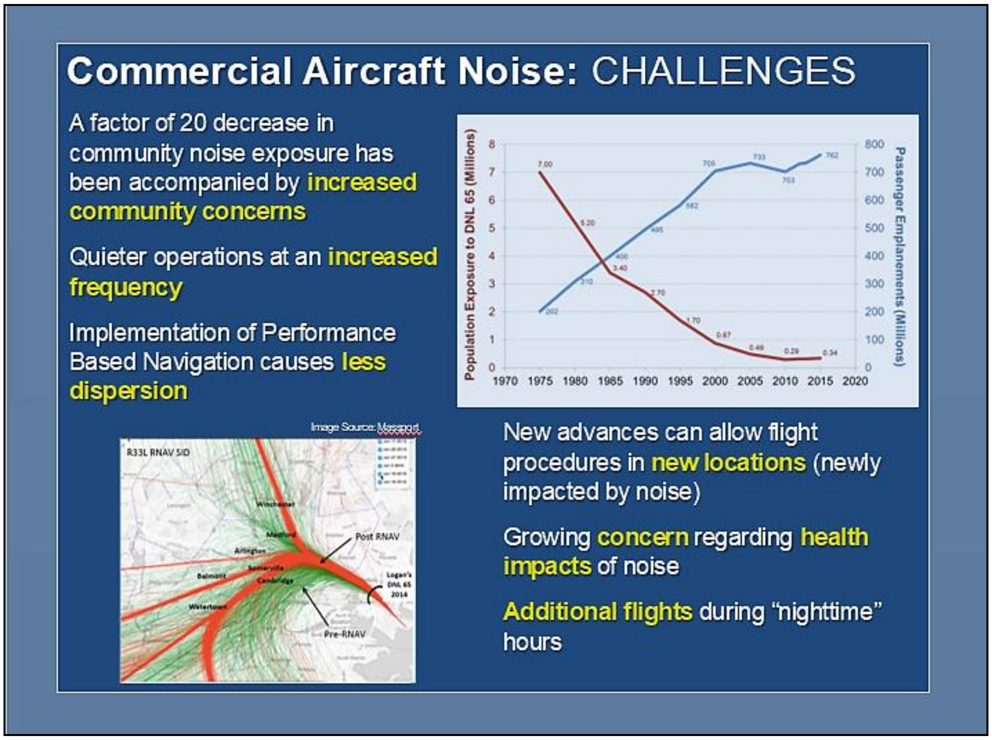

Figure 3.1-5 *Aircraft Noise Challenges*

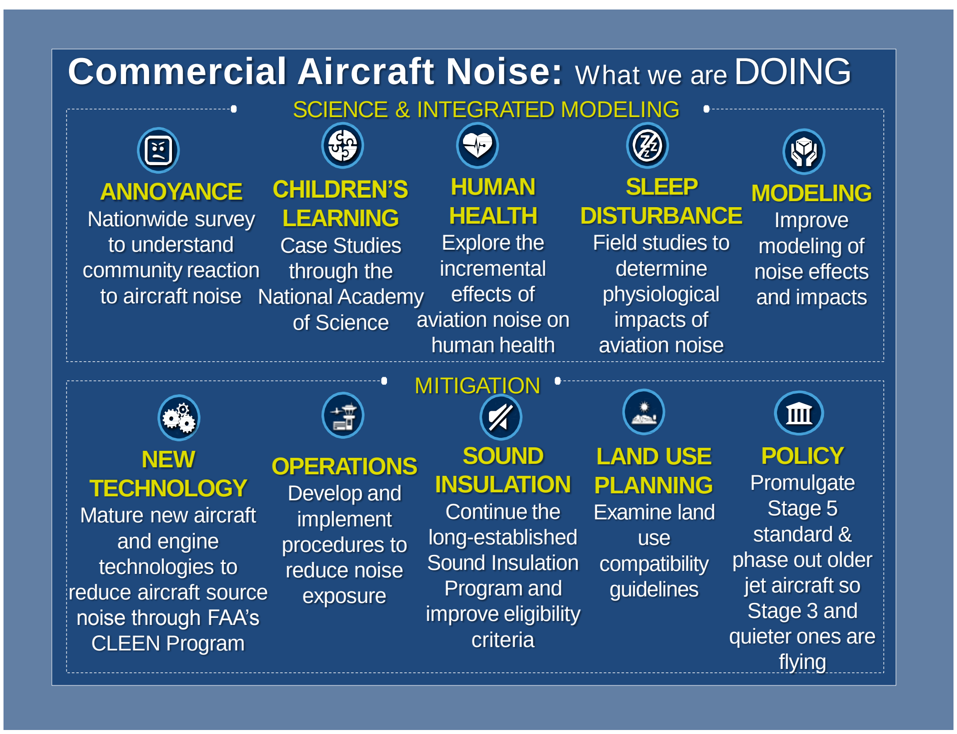

Figure 3.1-6 *Commercial Aircraft Noise: FAA Areas of Focus*

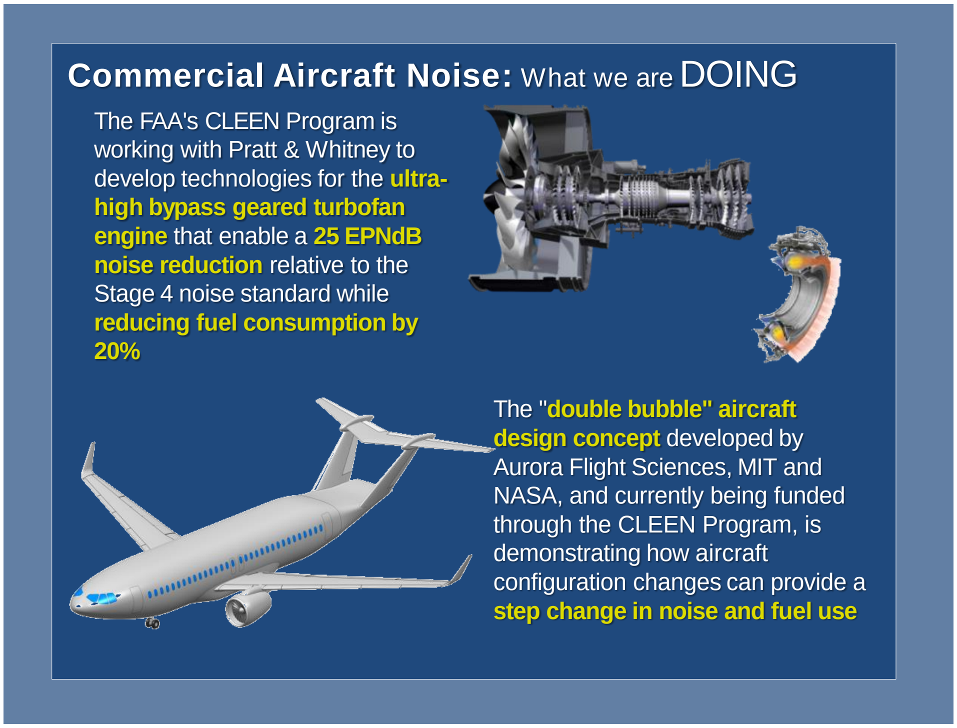

Figure 3.1-7 *FAA's CLEEN Program*

Figure 3.1-8 *Burleson Concluding Remarks*

3.2 FAA Perspective on the Challenges Posed by Aircraft Noise

James Hileman—*FAA*

Smart engine designs, coupled with airframe improvements for aerodynamic efficiency, have reduced noise along with fuel burn over the last half-century. Noise issues nonetheless linger, restricting the growth of the aviation industry. And challenges are in some ways magnified by the introduction of precision navigation that focuses flights into narrow corridors. In collaboration with private companies and academic institutions, the FAA is studying noise impacts using tools such as increasingly sophisticated modeling approaches. But a step change in environmental performance may only be accomplished through substantial aircraft reconfiguration.

James Hileman, Chief Scientific and Technical Advisor for Environment and Energy at FAA, spoke about challenges associated with aircraft noise and possible solutions—beginning with a look at historical noise trends and how accomplishments to date have fallen short of resolving the problem. In terms of potential solutions, Hileman's discussion would cover improvements in knowledge (using cutting-edge modeling tools, for example); advances in technology; and mitigation measures.

Hileman summarized two important metrics: 1) the EPNdB noise metric, measured at takeoff, sideline, and landing phases to determine perceived noise level which has been used for aircraft certification; and 2) day-night noise level (DNL), which considers the number of operations along with individual flight noise averaged over 24 hours with a 10 dB adjustment for nighttime flights and has been used to ascertain whether land use around an airport is compatible.

The presenter mentioned the "amazing improvement" in aircraft and engine technology over the last half century or so, from the very loud Boeing 707s and 727s of the early years of that time frame—which he characterized as "very low bypass" and "basically turbojets"—to current designs. The evolution in commercial aircraft and associated certified noise level is shown in Figure 3.2-1. Hileman attributed the "dramatic change" seen over time to intelligent engine design. Aircraft and engine manufacturers, Hileman said, have understood that the high specific thrust of the early days meant high fuel burn, and that changing the materials at the engine's core would allow for higher temperatures inside and, in turn, lower exit velocity and lower engine exhaust noise.

The goal was improvement in fuel burn, but noise likewise declined—a "win-win," according to the speaker. Airframe manufacturers have meanwhile made aerodynamic improvements, eliminating unnecessary slots and working to maintain performance with a cleaner aerodynamic configuration. Again, the changes have resulted in less noise, in addition to less fuel burn as well as simpler operation and maintenance.

Pointing to dramatic reductions in aircraft noise since the 1970s, as shown in Figure 3.2-2, Hileman stated, "While the aircraft noise reduction has been necessary in order to get where we are today, it's not sufficient to meet the needs of tomorrow." Hileman mentioned GAO reports in 2000 and 2010 noting delays in airport expansion projects—a quarter of them due to environmental issues (which translates, Hileman said, into noise). Even before RNAV, noise issues slowed the ability of aviation to grow, Hileman stated. With precision navigation, aviation expansion was additionally challenged.

Hileman next discussed day-night noise level, which looks at individual sound events over a 24-hour period to determine an integrated average. DNL 65 is the U.S. government's standard for measuring aircraft noise significance. Figure 3.2-3 depicts how DNL changes with increasing and decreasing operations. The change in DNL number is very dependent on the starting point, Hileman pointed out. Not surprisingly, he said, studies conducted in Europe found that those who suddenly experienced aircraft noise found it to be more annoying than those with a long experience with such noise.

Precision navigation concentrating flight tracks into narrow corridors has resulted in noise increasing quickly at some locations, though to relatively modest levels less than 65 DNL. With the increase in number of operations, reaction is coming even from areas far outside of the area with DNL 65. "It points to the challenge we have in front of us," Hileman said. "We already have very quiet aircraft, but they need to be quieter."

The FAA and others have addressed the challenge of aircraft noise from the perspectives of understanding impacts; outreach; and mitigation. These approaches are summarized in Figure 3.2-4.

The FAA has programs to study noise impacts. For attendees interested in this topic, Hileman recommended the ICAO Committee on Aviation Environmental Protection (CAEP) environmental report *Aviation Noise Impacts: State of the Science*. The report, whose lead author is workshop presenter Mathias Basner with the University of Pennsylvania, was written from a "high-level, state-of-the-science" perspective in language appropriate for the policy maker or other non-specialist, Hileman said.

The presenter elaborated on the FAA's projects looking at noise impacts in these four areas:

- *Annoyance.* A comprehensive community survey of some 10,000 people will provide scientific data about annoyance and DNL, and provide the basis for re-evaluating the federal noise significance level.
- *Sleep Disturbance.* Through its Centers of Excellence, the FAA is working to quantify the impact of aviation noise on sleep.
- *Cardiovascular Health.* Leveraging information from large epidemiological studies, the FAA is interested in statistically determining whether a correlation exists between noise exposure and cardiovascular disease.
- *Children's Learning.* Through the National Academies' Airport Cooperative Research Program, the FAA is studying the impact of aircraft noise on children's learning. Mitigation through sound insulation could represent a possible solution, Hileman said. http://apps.trb.org/cmsfeed/trbnetprojectdisplay.asp?projectid=3693

Turning to the subject of modeling, Hileman spoke about the FAA's Aviation Environmental Design Tool (AEDT), created over a period of roughly a decade for use in regulatory actions, including those related to noise and also fuel burn and emissions. Additional work is needed, as the current version AEDT2c is based on the Integrated Noise Model (INM) focusing on DNL 65, and noise must also be modeled for a lower DNL. Collaborative work is ongoing to improve takeoff weight and thrust modeling, improve the aircraft performance module, and lay the groundwork to incorporate airframe noise more explicitly.

Next, Hileman briefly discussed the operational issues of where, when, and how aircraft are flown. Here, the FAA's work to advance modeling capabilities is important to examine opportunities for noise abatement in areas such as thrust and speed management and vertical profile, as summarized in Figure 3.2-5. Figure 3.2-6 provides an additional synopsis of modeling operational improvements currently under study by the FAA and its partners. Questions being studied include: How does changing the aircraft, or slowing it down earlier or later, affect noise on the ground?

After a brief summary of the CLEEN I and CLEEN II programs, which were also discussed by other presenters, the speaker concluded by talking about the need to reconfigure aircraft. They have long stuck to a classic design—with swept wings, aft tail, and usually the engines mounted underneath the wing—and could use a design upgrade that optimally integrates engine, airframe, and operations. A step change in noise reduction will only be achieved if it is accompanied by a step change in fuel burn while ensuring safe operation he said, as summarized in Figure 3.2-7. The speaker also made a "pitch" for low-noise, single-aisle aircraft, which could provide substantial reduction in the noise exposure as depicted in Figure 3.2-8.

In conclusion, the speaker reiterated that noise remains a constraint on growth. "Technology is needed" to address this problem, he said, adding that "this particular challenge is incredibly well-suited, in my humble opinion, to industry and government working again together through a public/private partnership."

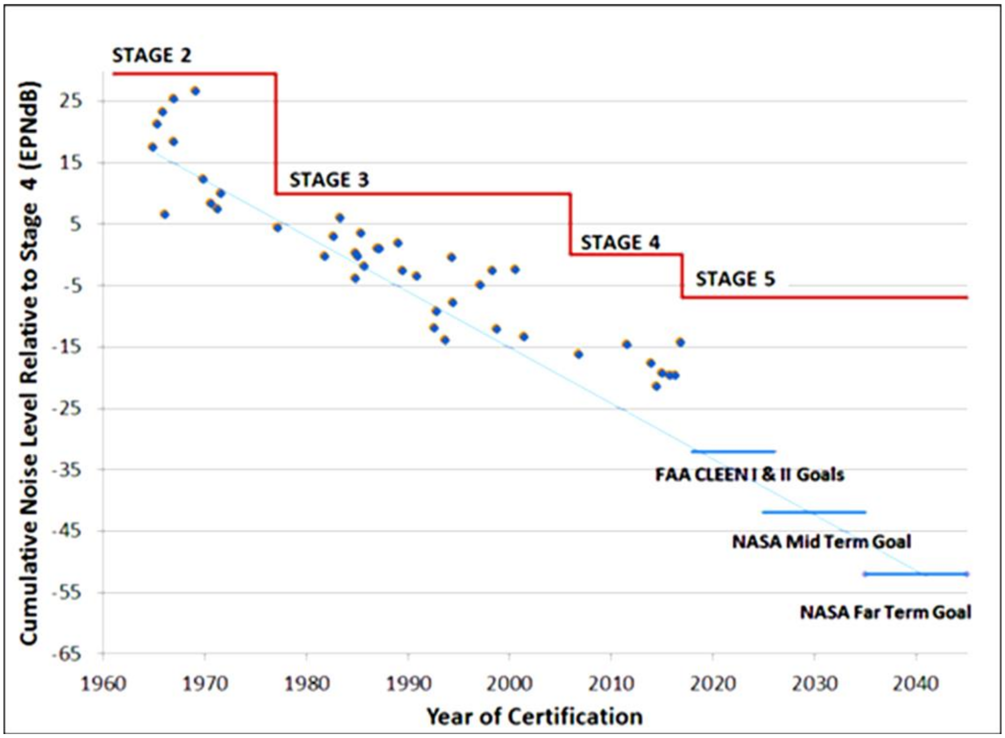

Figure 3.2-1 *Progression of Aircraft Noise over Decades*

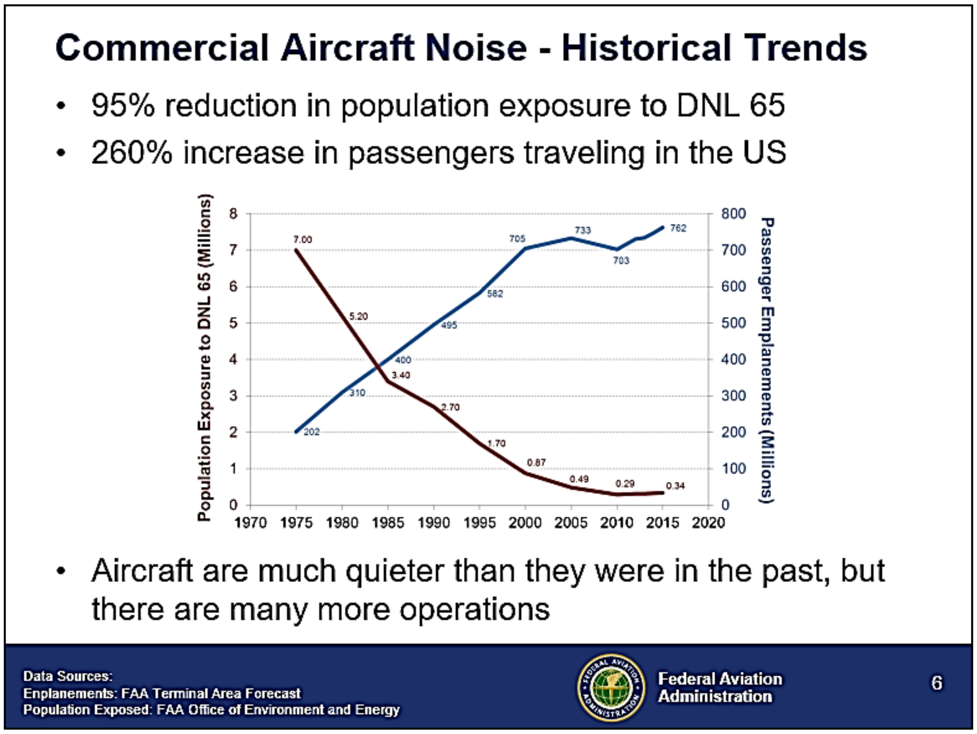

__Figure 3.2-2__ Trends in Aircraft Noise and Passenger Travel

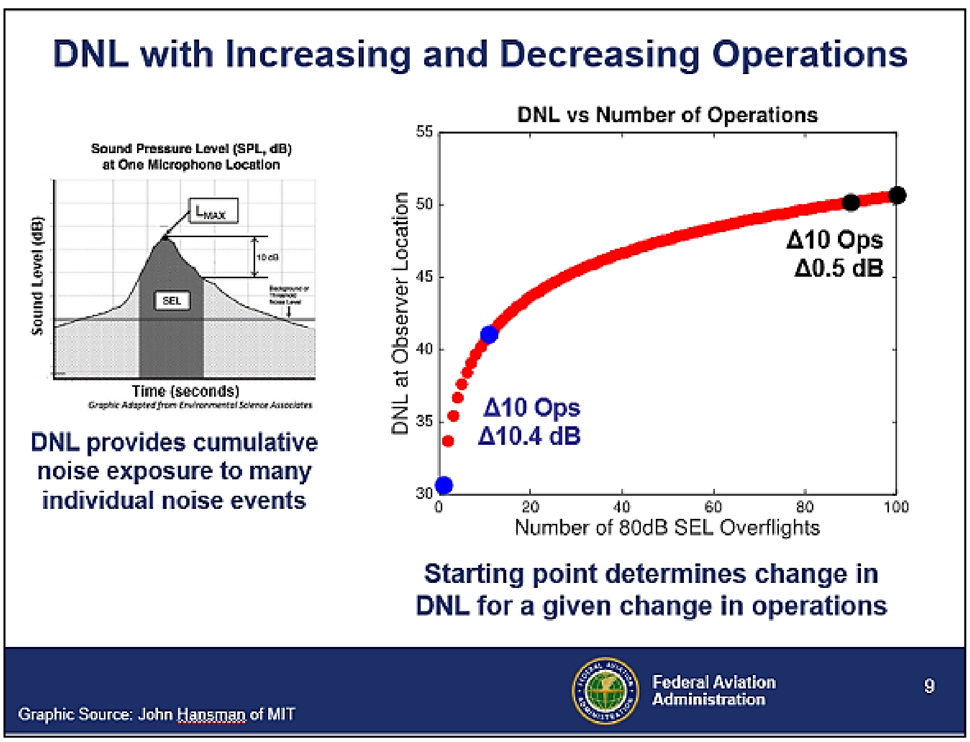

Figure 3.2-3 *DNL with Changing Number of Operations*

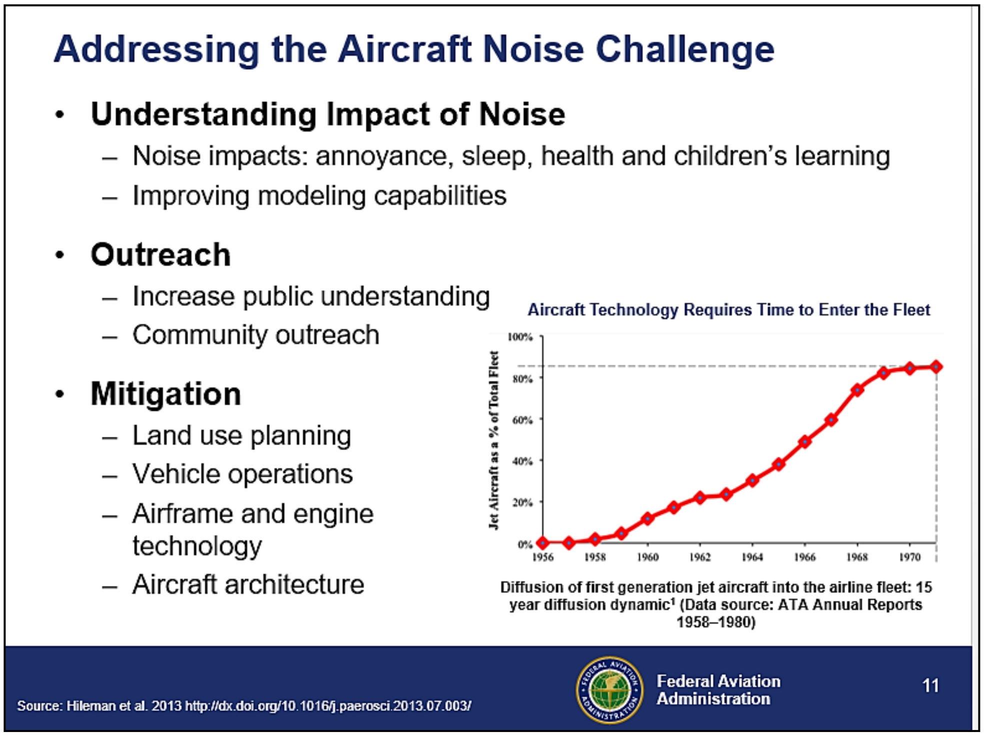

Figure 3.2-4 *Addressing the Noise Challenge: Three Facets*

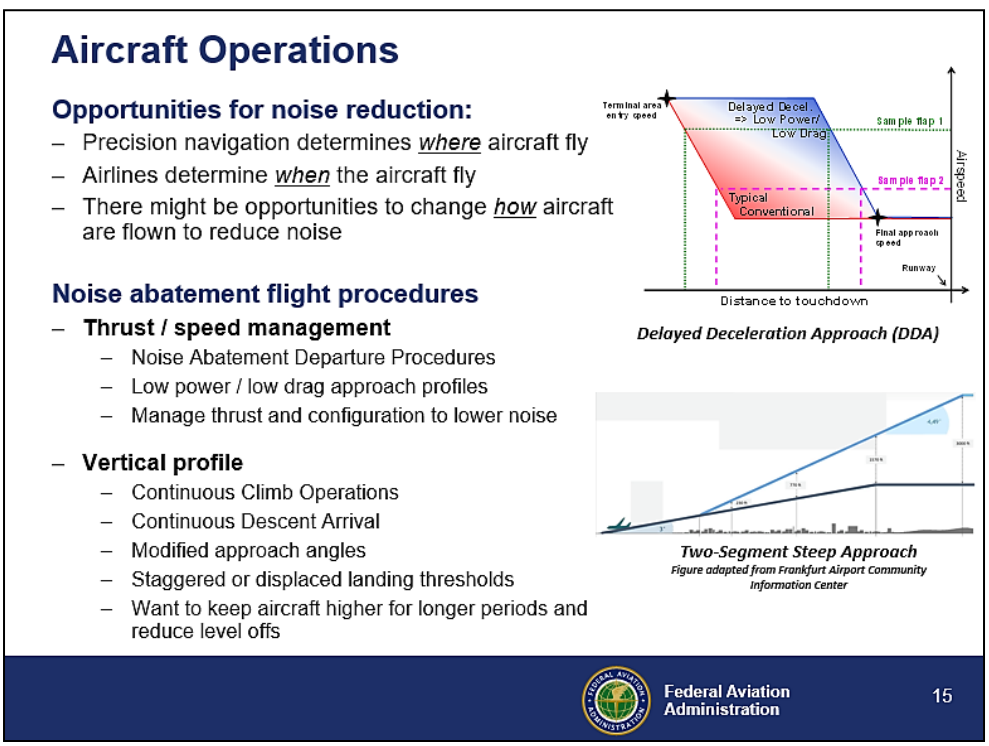

Figure 3.2-5 *Aircraft Operations and Noise Reduction*

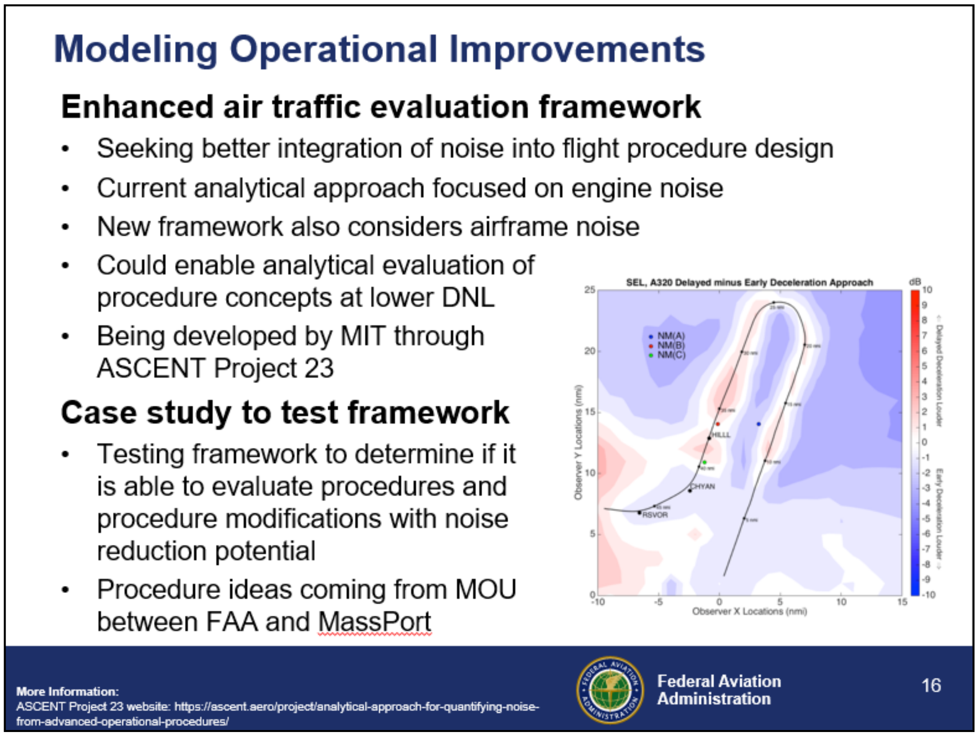

Figure 3.2-6 *Modeling Changes in Operations*

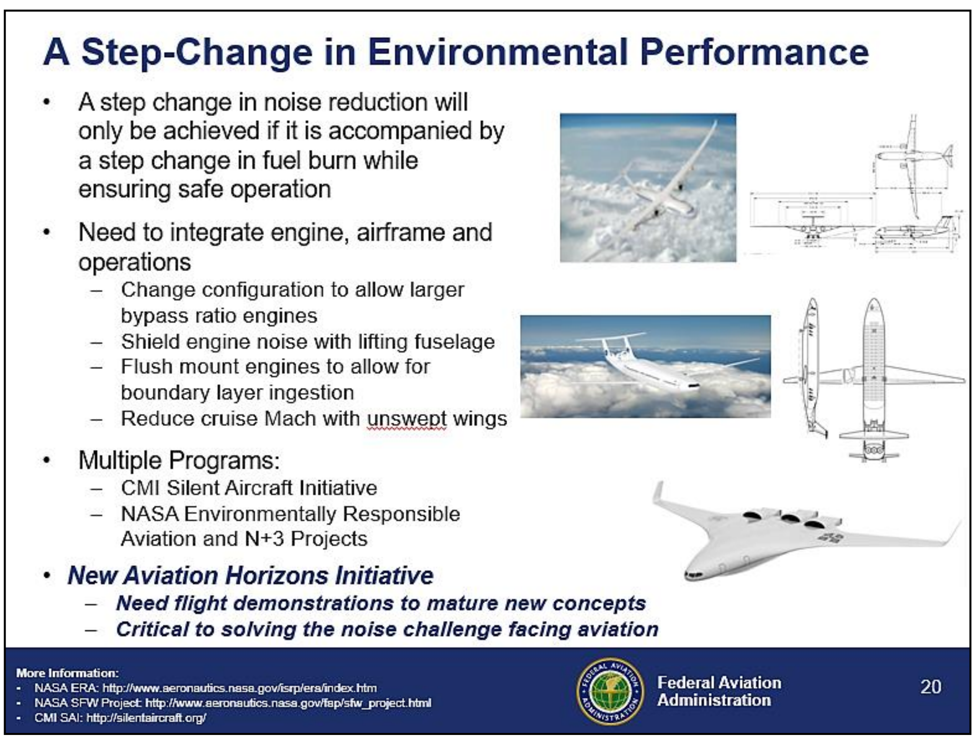

Figure 3.2-7 *Step Change in Noise: What Will It Take?*

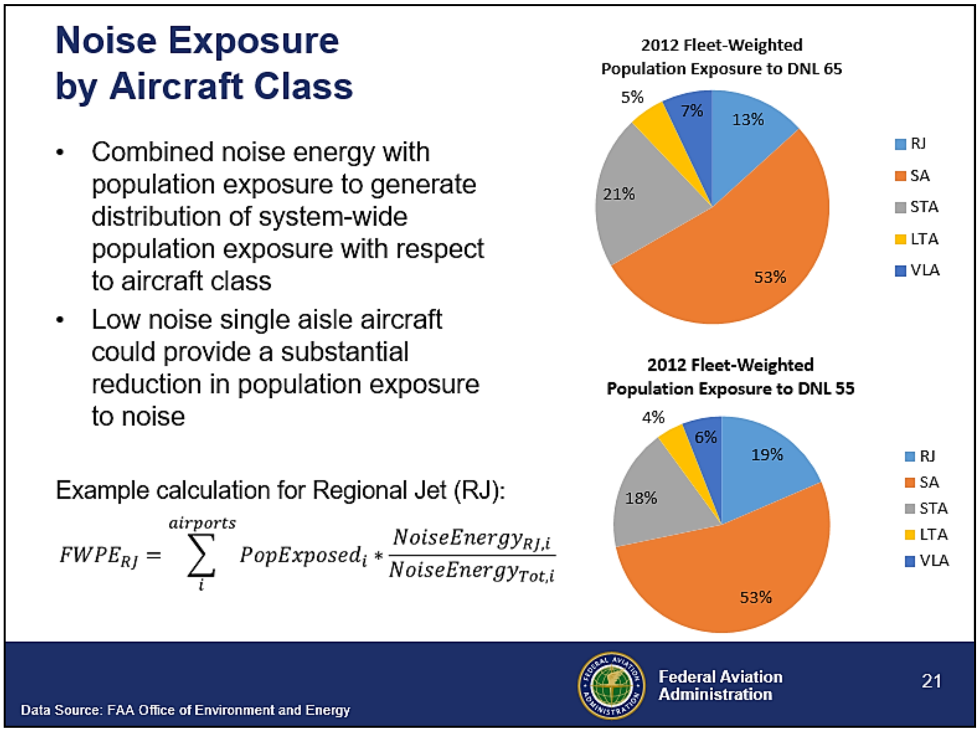

Figure 3.2-8 *Aircraft Class and Noise Contribution*

3.3 The Future of Aviation: The NASA Strategic Plan

Jay Dryer—*NASA*

The NASA aeronautics program has led many pioneering advances in U.S. aviation, often in collaboration with other government agencies, private industry, and academic institutions. In both vehicle and operations research, NASA relies on a building-block approach to understand a problem, set ambitious goals, and progress a project to an appropriate point for U.S. industry or others to embark on development of cutting-edge aviation products.

Jay Dryer, Director of the NASA Advanced Air Vehicles Program, provided an overview of the NASA aeronautics research portfolio and strategic approach. NASA programs do not work in isolation, the speaker emphasized, but rather very collaboratively.

Early in the presentation, Dryer introduced the overall NASA aeronautics strategy which, some five years ago, resulted in the creation of six "strategic thrusts." He described these strategic thrusts, which are presented in Figure 3.3-1.

Strategic Thrust 1: Safe, Efficient Growth in Global Operations. The primary focus is improvements in operations for increased efficiency, and environmental factors, such as noise, are among the important considerations.

Strategic Thrust 2: Innovation in Commercial Supersonic Aircraft. The focus is on opening a new civil supersonics market. The initial focus is on establishing a low sonic boom standard, but research also covers areas such as reducing jet noise for these systems. Research in a specific area such as supersonics can benefit the broader market.

Strategic Thrust 3: Ultra-Efficient Commercial Vehicles. This area covers a broad range of vehicles and includes research to reduce noise for both fixed-wing and vertical-lift vehicles.

Strategic Thrust 4: Transition to Alternative Propulsion and Energy. The focus is on enabling new propulsion concepts to improve efficiency and support additional capabilities.

Strategic Thrust 5: Real-Time System-Wide Safety Assurance. This strategic thrust supports the critical area of safety by taking advantage of new capabilities in data analysis and prognostics.

Strategic Thrust 6: Assured Autonomy for Aviation Transformation. The aim is to capitalize on the growing power of autonomy applications to aviation's benefit.

Next, Dryer discussed how these thrusts are organized within the structure of the Aeronautics Research Mission Directorate (ARMD), which classifies programs as either mission or seedling programs, as shown in Figure 3.3-2.

The *Airspace Operations and Safety Program* has primary responsibility for operations-related research and coordinates closely with the FAA.

The *Advanced Air Vehicles Program* focuses on vehicle-specific technologies across a broad range of classes.

The *Integrated Aviation Systems Program* focuses on research on vehicles and operations as they apply to flight.

The *Transformative Aeronautics Concept Program* is the sole seedling program developing new ideas for possible transition to the mission programs. This program is also responsible for key cross-cutting research that includes tools development. The Aircraft NOise Prediction Program (ANOPP) is an example of such a tool.

Notably, Dryer said, NASA Aeronautics does not develop specific products and does not have an operational mission. Rather, it provides the knowledge, tools, technologies, and capabilities to allow others—particularly, U.S. industry—to develop products. NASA has been a contributor in the case of almost every major U.S. aviation product, said Dryer, pointing to examples listed in Figure 3.3-3 of NASA technologies inherent in aviation as we know it.

Dryer introduced engine nozzle chevrons as an example of a noise reduction technology that NASA played a key role in developing. Figures 3.3-4 and 3.3-5 summarize the technology and its development path, which the speaker noted was a long process given the complexities. Early on, seedling efforts advanced the understanding of the noise generation mechanisms and whether nozzle shaping could be used to improve mixing. Understanding the physics was key, as was the chevrons' shape, given that an improper design could have exacerbated the noise problem rather than managing it. A later step involved comprehensive ground and flight tests, which paved the way for creation of products.

Importantly, Dryer pointed out, NASA was not seeking a point solution, but was instead focused on understanding the physics involved and taking on the role of providing guidance and potential paths to nozzle designs with significant noise reduction benefits in various applications.

As described in Figure 3.3-6, NASA has used a building-block approach for both vehicle and operations research to better understand a problem, set high-reaching goals, and progress toward technology development culminating in larger system demonstrations. For vehicle research, a key step was initiating a series of studies of "N+3" in the 2008 time frame. The purpose was to challenge NASA experts and the broader community to identify key technologies for significant performance and environmental benefits. After progressing from studies and largely analytical work to key ground experiments, the project has reached the cusp of advances in the form of actual leading-edge "X-planes." NASA's approach, Dryer said, explains how the agency successfully advocated for the New Aviation Horizons Initiative, which strives to develop the series of cleaner, quieter, and faster X-planes. Committed NASA efforts have developed key operational capabilities that have culminated in large integrated demonstrations.

Next, Dryer discussed a key aspect of the NASA strategy: establishment of sophisticated metrics to guide research. For example, a series of subsonic metrics was developed and used in the N+3 studies. The main purpose, Dryer explained, was to open up the trade space for innovative aviation capabilities.

Dryer left specific discussion of X-planes to the session devoted entirely to this topic. He mentioned, however, that NASA is exploring several technologies—the X-plane configuration itself among them—that NASA has proven can have tremendous benefits.

To explore and develop key technologies, the presenter explained, NASA generally takes a three-pronged research approach using computational tools, ground testing, and flight testing. This approach has been instrumental in the advances that rendered the New Aviation Horizons practical.

Dryer highlighted the substantial improvements over the past several decades in aviation noise that is shown in Figure 3.3-7. NASA goals, which build on this trend of improvement, are very aggressive and promise tremendous benefits, the speaker said.

Partnerships with other government agencies, industry, and academia have been critical to NASA's successes, Dryer stressed. An example of an extremely strong government affiliation:

the NASA-FAA partnership. NASA supports FAA activities such as the Continuous Lower Energy, Emissions, and Noise (CLEEN) Program. And the FAA is heavily involved in NASA research planning and evaluation. The industry and university sectors, too, have helped NASA stay on the cutting edge of technologies. Noise is one key aspect among many that present exciting opportunities and great promise for benefiting aviation, Dryer concluded.

Figure 3.3-1 *NASA's Strategic Thrusts*

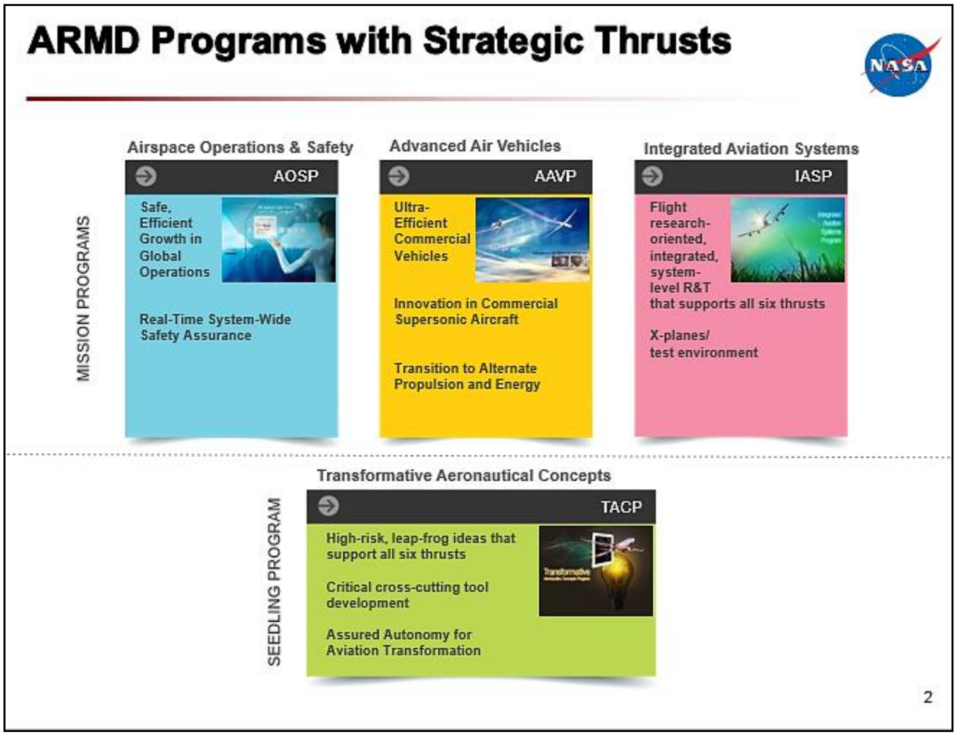

Figure 3.3-2 *Thrusts Classified Under ARMD Programs*

Figure 3.3-3 *Examples of NASA's Continuing Contributions to Aviation Technology*

Figure 3.3-4 NASA-Supported Advance: Chevron Nozzles

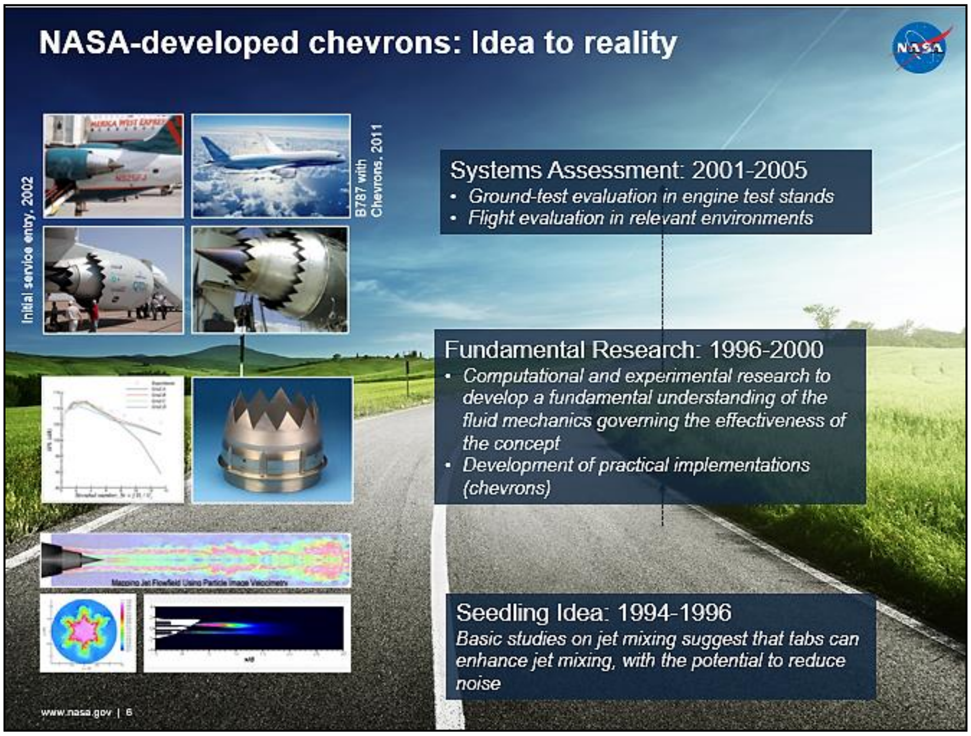

Figure 3.3-5 How NASA Developed Chevron Nozzles

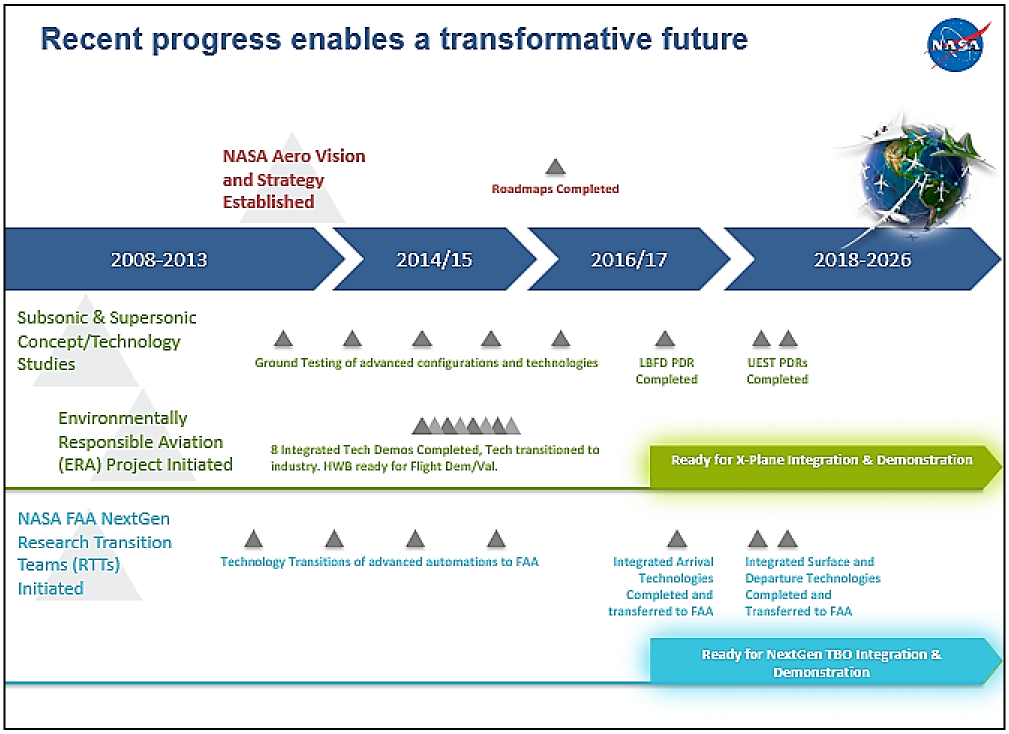

Figure 3.3-6 *Building Blocks of Progress*

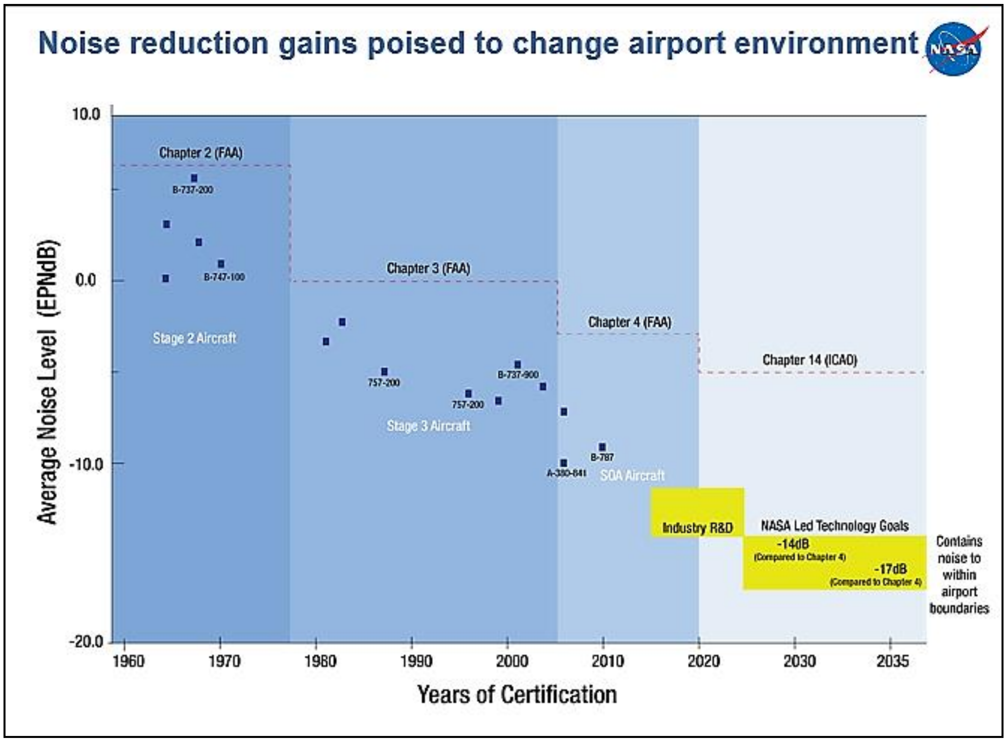

Figure 3.3-7 *Decades of Aviation Noise Reduction*

3.4 X-Plane History—the X-48C, and Beyond

Edgar Waggoner—*NASA*

NASA-developed X-planes—starting with the X-1 series and reaching a turning point with the X-48—exemplifying the agency's leading-edge research and resulting aeronautical innovation. NASA's futuristic experiments in areas such as electric, subsonic, and supersonic aircraft have advanced U.S. military capabilities. Meanwhile, these efforts—often undertaken as government-industry partnerships—have also benefited commercial aviation by scaling down risk for developing technologies to levels acceptable to the private sector.

Edgar Waggoner, Director of NASA's Integrated Aviation Systems Program, began by outlining the content of his presentation. The speaker would focus on NASA's plans for its X-plane research vehicles, including electric aircraft, supersonics, and ultra-efficient subsonic transport aircraft. The presenter would lead up to this primary discussion with some historic background about the demonstrators, including recent successes with the X-48 aircraft; X-planes' place in aeronautics research and development; and NASA's role in these advances.

As summarized in Figure 3.4-1, X-planes were borne out of the post-World War II environment. In the Cold War-era aeronautics "battleground," it was a priority for the U.S. to retain leadership in the commercial, and especially the military, aeronautics realms. To dominate in aeronautics required a stepped-up emphasis on flight research.

One key issue was how aircraft behave in the transonic speed regime around Mach 1. Ground testing facilities could test in this transonic regime, Waggoner explained, but questions about flight in these conditions remained unanswered, and represented the impetus for the development of the first series of experimental aircraft, the X-1A through X-1E. These research vehicles were the first to break the sound barrier in level flight, Waggoner said: And so began the "X-plane legacy."

The speaker next mentioned the X-5 research vehicle, the first aircraft to fly with variable wing sweep. "You unsweep the wings for low-speed flight, takeoff, and landing," Waggoner explained, "and then trying to keep that leading edge below Mach 1, you sweep the wings back as you go faster." This aircraft was a predecessor to the F-14, the research vehicle that provided fundamental boundary layer stability measurements in flight.

After some additional history about the intervening years, the presenter highlighted achievements from the 1960s to 1990s, an era during which X-planes were built primarily to test military technologies. Research vehicles during this time tested lifting bodies for space flight, reusable spacecraft, the tilt rotor, and other critical technologies, as summed up in Figure 3.4-2. In collaboration with Grumman, NASA collected qualitative data by using a tufted fuselage and wing. The X-31 "key program" followed, focusing on thrust vectoring and super-maneuverability, Waggoner said, toward important advancements in fighter vehicles.

The early 2000s saw another groundbreaking series of technology demonstrators under a Department of Defense/Defense Advanced Research Projects Agency/industry collaboration. The X-35, the independent joint strike fighter, was among the new demonstrators, along with the X-45, X-51, and X-55 as described further in Figure 3.4-3.

After briefly highlighting a shift in NASA's focus during the 2005-2006 time frame to include environmental impacts such as emissions, fuel burn, and noise (as was discussed in greater detail in Jay Dryer's presentation), Waggoner continued his discussion of specific research vehicle advances.

The X-48B blended wing body aircraft was characterized by winglets for lateral stability, three engines, and its propulsion systems. A key interest with this vehicle class, Waggoner explained, was low-speed stability and control. Even with the promise of transonic benefits, concerns existed about operations such as takeoff and landing, at the "edges of the low-speed envelope." With the X-48C, a new propulsion system allowed the use of two engines instead of three. What's more important, moving the vertical stabilizers inboard provided "big benefits" by shielding the ground from noise. Figure 3.4-4 shows pictures of these blended wing X-48 aircraft and associated data.

From this work related to propulsion airframe integration, lightweight structures, and full systems, NASA showed it was possible to reach 50 percent fuel burn reduction, emissions reductions on the order of 80 percent, and 42 dB cumulative noise reduction in cruise, landing, and takeoff phases.

From there, NASA made the case for a national imperative to build on these aeronautics successes, which would include training its engineers and a new generation of flight researchers. The last budget under the Obama Administration significantly upped federal investment over an unprecedented 10-year time frame, and required a NASA investment plan to lay out how the investment would be handled. The NASA plan included a focus on key technologies that would be developed to a technology readiness level so risk for commercial aviation would be reduced to an acceptable point. With less risk, technologies holding promise for commercial flight would be assisted in crossing the so-called "valley of death."

Next, Waggoner addressed the potential benefits of electric propulsion systems, which hold promise for the environment and energy efficiency. The potential benefits, in a nutshell: a 60 percent energy use reduction, a 90 percent reduction in harmful emissions, and a 65 percent reduction in noise. The X-57 Maxwell, which is being developed as the first all-electric airplane, is intended to demonstrate the benefits of distributed electric propulsion for efficiency, emissions, and noise. See Figures 3.4-5 and 3.4-6.

Focusing next on supersonics, Waggoner stated that work over the last 15 years or so has shown a "tremendous benefit" in terms of reducing noise, but that realizing this promise is impossible under current constraints on supersonic flight over land. NASA is interested in flying a demonstrator and soliciting community response so that the FAA and the International Civil Aviation Organization can make informed policy decisions in this regard. Waggoner pointed to data gathered already, as summarized in Figure 3.4-7, that supports readiness for flight of NASA's low-boom supersonic technology. NASA is finalizing the preliminary vehicle design and will soon open up a request for proposals for the next design and build phases.

Waggoner next discussed NASA's current thinking related to Ultra Efficient Subsonic Demonstrators. Figure 3.4-8 shows some configurations that have been considered—specifically, the truss-braced wing, the D-8 "double bubble," and the hybrid wing body—and their benefits. Lockheed Martin and Boeing have each been working on their own configurations for military and/or commercial transport. Waggoner stated, "We've been working very closely with U.S. industry to make sure we understand what needs to be done and the right way to do this work."

As the presentation neared its end, Waggoner emphasized that NASA's leading-edge plans for aviation are "doable," assuming the planned budget is sustained. Steps over the next 10 years are laid out in Figure 3.4-9. NASA believes it can publish a Request for Proposal around fiscal year 2024 for the next-generation subsonic vehicle. "The point here is, we're going to take a very measured serial approach to these demonstrators," Waggoner stated. The collaboration between federal government, industry, and academia means NASA aeronautics is "poised for a great return on investment." NASA aeronautics is readying itself, Waggoner concluded "for the next 100 years of work to benefit our nation."

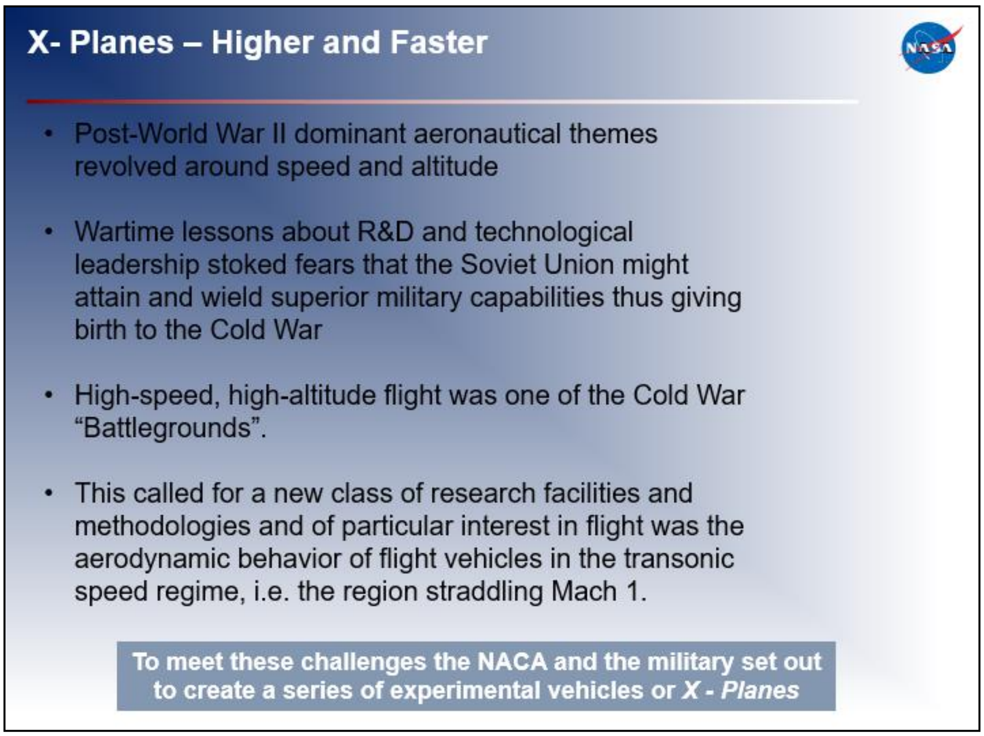

Figure 3.4-1 *Post-War Aeronautics Themes: Fly Higher, Fly Faster*

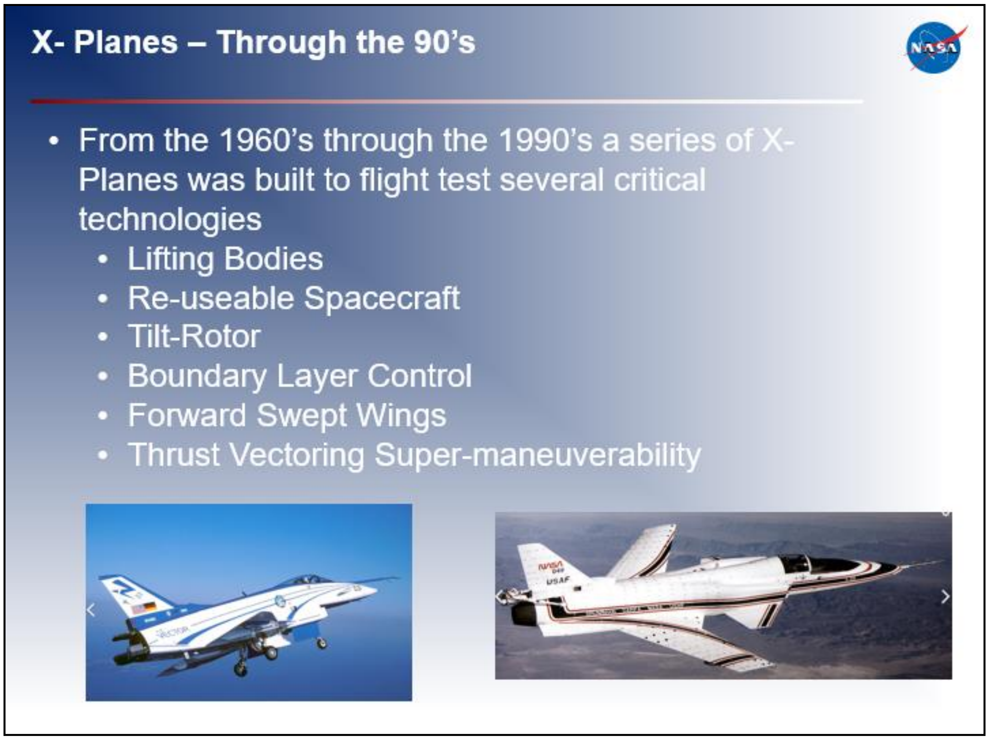

Figure 3.4-2 *X-Plane-Tested Technologies, 1960s–1990s*

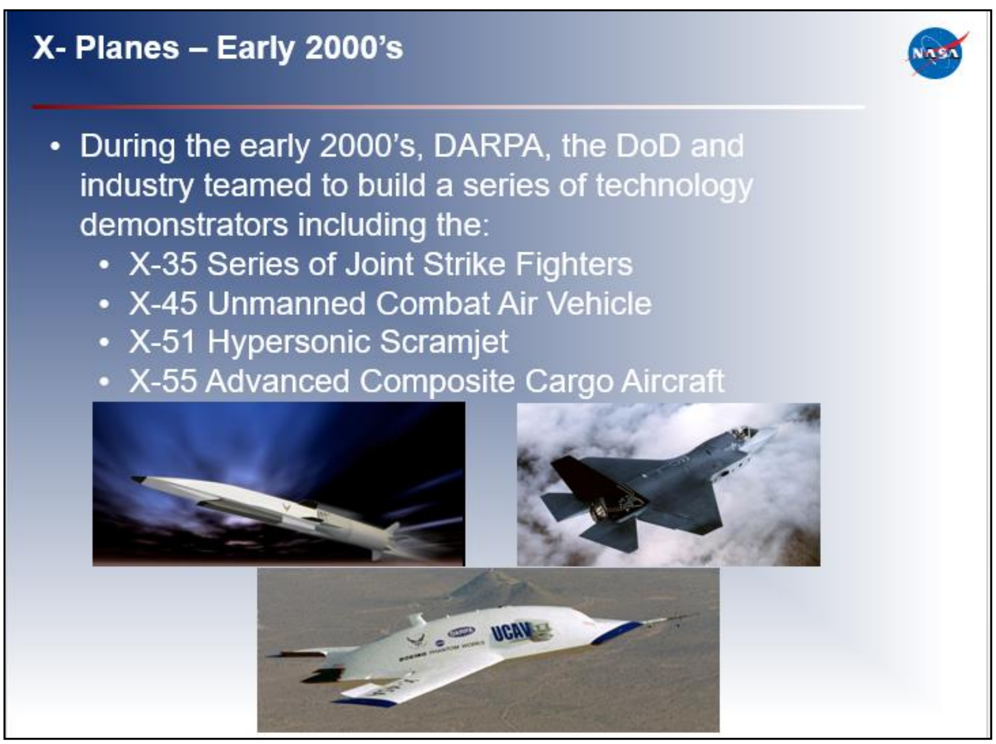

Figure 3.4-3 *Next Phase of Technology Demonstrators, Early 2000s*

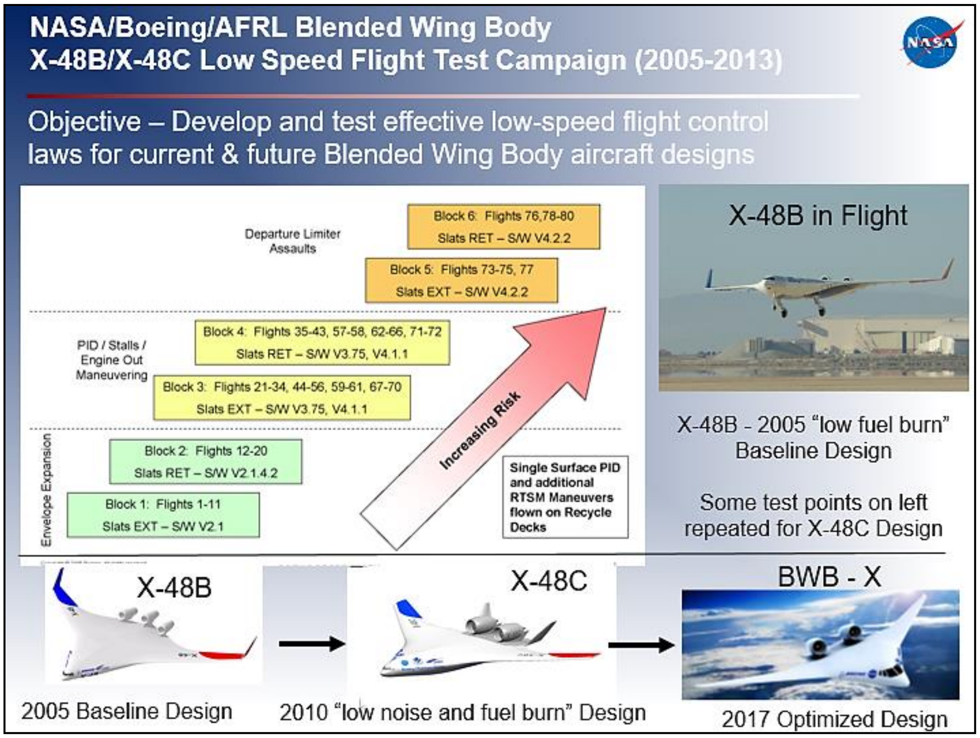

Figure 3.4-4 *Testing Blended Wing Body in Low-Speed Flight*

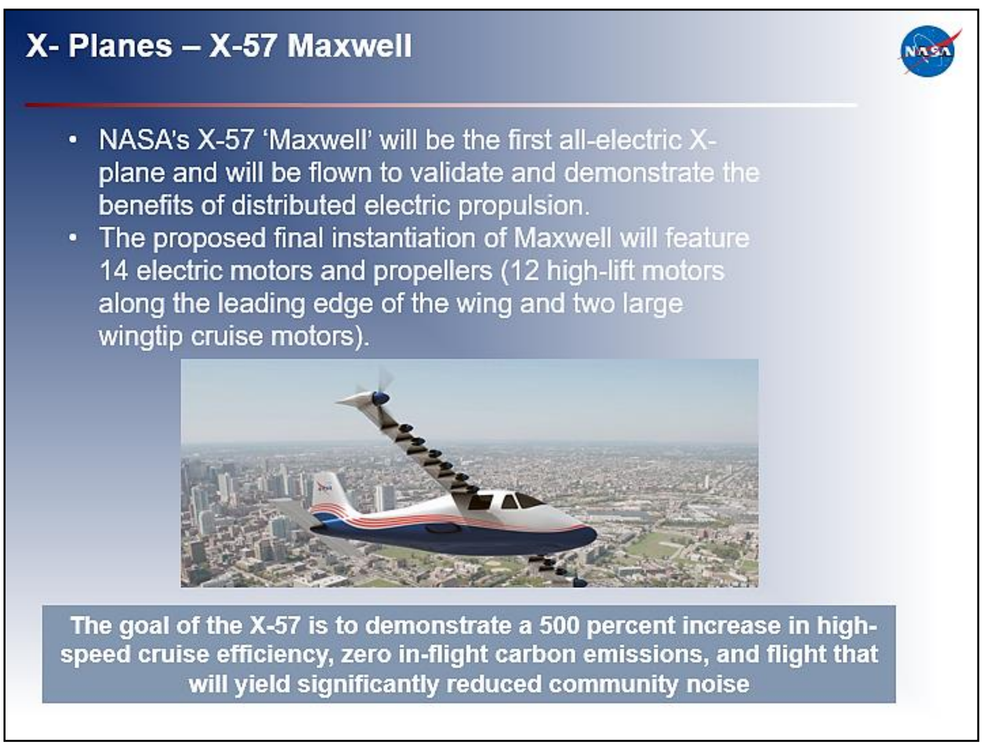

Figure 3.4-5 *X-57 Maxwell: The First All-Electric X-Plane*

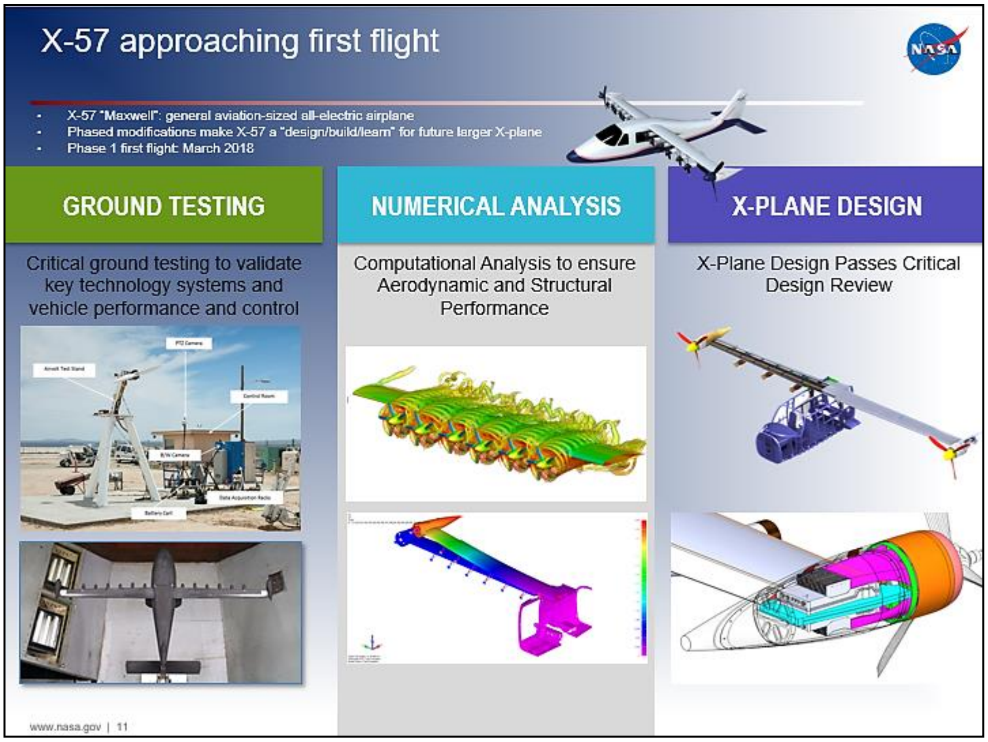

Figure 3.4-6 *X-57 Approaching first flight*

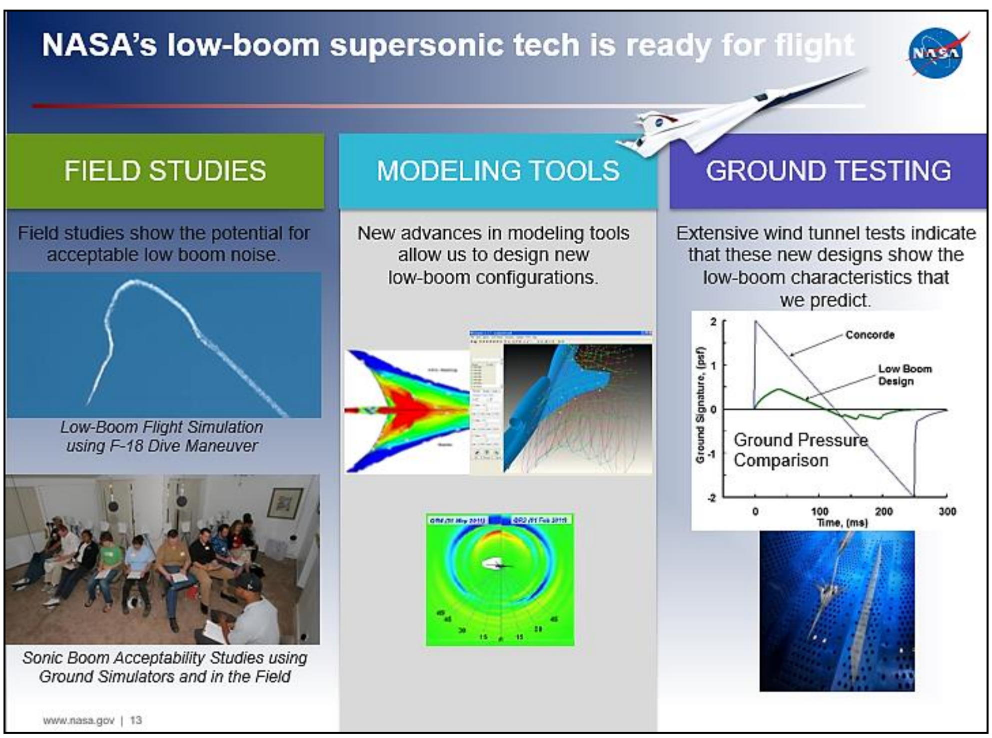

Figure 3.4-7 *Low-Boom Supersonic Technology: Tested and Ready*

Figure 3.4-8 Ultra-Efficient Subsonic Configuration Options

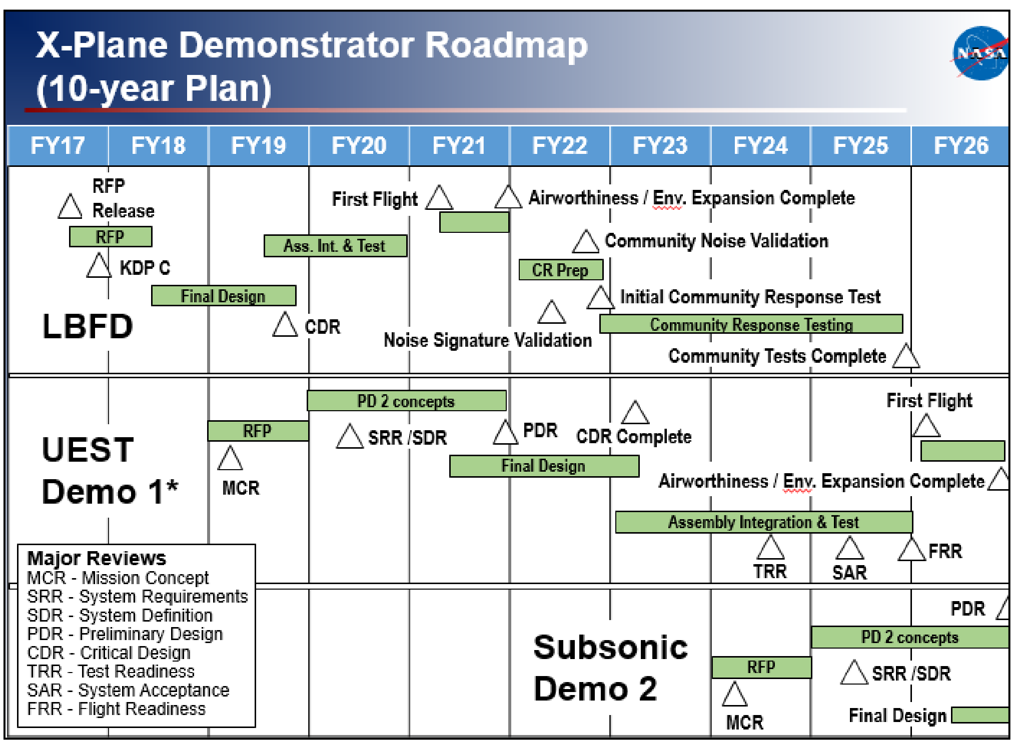

Figure 3.4-9 X-Plane 10-Year Roadmap

3.5 Engine Development: The Prospects for Future Engines—Quieter, Cleaner, and Environmentally Protective

3.5(a) Engine Development: The Prospects for Future Engines—Quieter, Cleaner, and Environmentally Protective *(Presenter 1 of 2)*

Michael Winter—*Pratt & Whitney*

For more than 90 years, Pratt & Whitney, a division of United Technologies Corporation, has manufactured engines that power the world's commercial and military aircraft. And the company has partnered for decades with NASA, FAA, and universities in developing advanced engine technologies for reduced fuel burn and reduced noise. Pratt & Whitney has helped position the United States as the premier provider of aerospace components. Among the benefits of the country's thriving aviation industry, which moves more than 3 billion passengers in a year, is a huge number of well-paid American jobs.

Michael Winter, Pratt &Whitney senior fellow for advanced technology, opened his presentation with a video of the propulsion systems on all Pratt & Whitney propelled aircraft. The company's early Wasp rotary engine, he explained, had the unique feature of being air cooled. Air cooling rather than water cooling resulted in more than doubling the engines thrust-to-weight ratio. Pratt & Whitney manufactured approximately half a million of these early engines during World War II, and it has been said that it was the engine that won the war.

The jet engine was introduced about 80 years ago. Advances in engine architecture since that time—from single spool to dual spool turbojet to high-bypass turbofan to the current ultra-high-bypass Pratt & Whitney PurePower® Geared Turbofan™ engine—have significantly increased overall efficiencies, as shown in Figure 3.5(a)-1.

"We are on the cusp of a new generation," Winter said, "with the recent introduction of yet a new architecture with ultra-high-bypass ratio with the geared turbofan, which entered service last year. It is currently flying on approximately 100 commercial aircraft in revenue service today on multiple airframes." The speaker went on to describe the geared turbofan engine illustrated in Figures 3.5(a)-2 and 3.5(a)-3.

Engine efficiency is a combination of propulsive efficiency and thermal efficiency. A paradox in twin-spool gas turbine engines is that generally speaking and within limits, the low-pressure turbine at the back of the engine always wants to spin as fast as possible for greatest efficiency, while the fan at the front of the engine wants to spin as slowly as possible for high efficiency. Introduction of a gear box with a ratio of about 3 to 3-1/2—developed in partnership with NASA and FAA—is now letting each one operate at its optimal efficiency. The gear ratio is carefully chosen as a trade on the basis of both propulsion system and aircraft optimization.

The geared turbofan architecture is about 16 percent more fuel efficient than earlier designs. Also, the noise footprint is reduced by 77 percent compared to earlier designs because the fan blade tip speed is reduced with the gearbox. Furthermore, with the low-pressure turbine spinning at its optimal speed, 48 percent of the airfoils have been taken out of the engine due to the higher delta pressure per stage allowing removal of several stages of rotating machinery. This combines with the fuel savings from efficiency to reduce airlines' operation and maintenance costs by $1.5 million to $2 million dollars per airplane per year. Winter said that major commercial airframes are being re-engined with this new technology.

Pratt & Whitney has examined noise footprints at airports for airplanes with and without the geared turbofan engines. Figure 3.5(a)-4 is an example for LaGuardia Airport. Potential benefits of the upgraded technology include direct flight paths, lower noise fees, and curfew extensions.

Winter went on to address trends in engine technology. During the last 80 years, a 375 percent increase in thermal efficiency has been achieved, as shown in Figure 3.5(a)-5. And, Winter said, "There is a bright future and a lot of opportunities for gas turbine propulsion. This will also drive the use of new materials to achieve some of these higher temperatures."

In partnership with NASA and FAA, Pratt & Whitney recently demonstrated FAA CLEEN engine with a fan pressure ratio of 1.3 that is equivalent to a 15 bypass ratio. While working with NASA, the company demonstrated a fan pressure ratio of 1.25 in a test cell, equivalent to an 18 bypass ratio. Even more important, this is being accomplished with shorter nacelles thereby reducing drag. These results pioneer technology insertion that goes even deeper into the design space of geared turbofan architecture resulting in even greater fuel efficiency for the future.

Pratt & Whitney and United Technologies Research Center are contributing to development of the important X-Planes at NASA. Its contributions include work related to boundary layer ingestion into the gas turbine engine.

Winter concluded by expressing excitement about prospects for the future of aircraft engines. Enhancing technology partnerships with universities, industry, NASA and the FAA through a national investment in aeronautics technology will help realize this future.

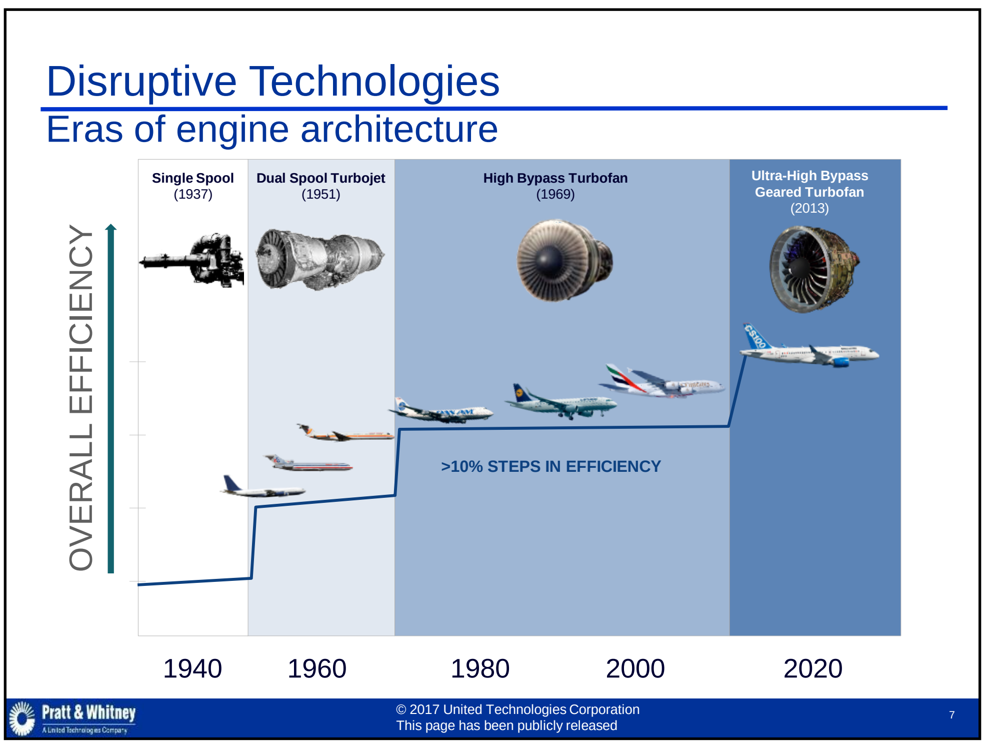

Figure 3.5(a)-1 *Overall Engine Efficiency vs. Time*

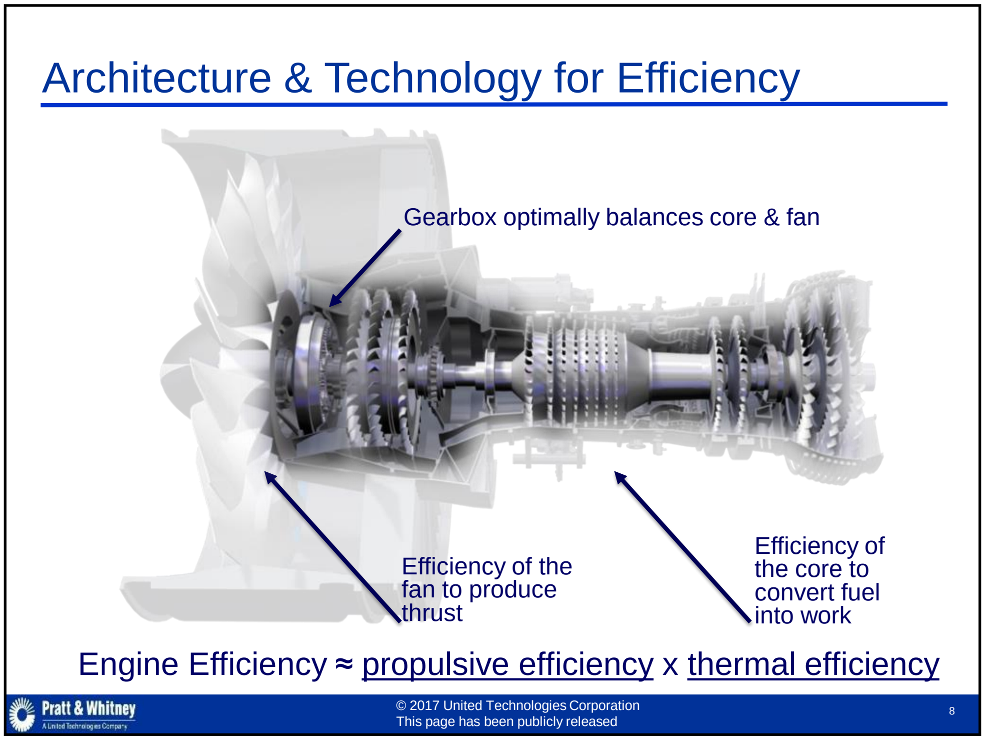

Figure 3.5(a)-2 *Architecture of Geared Turbofan Engine*

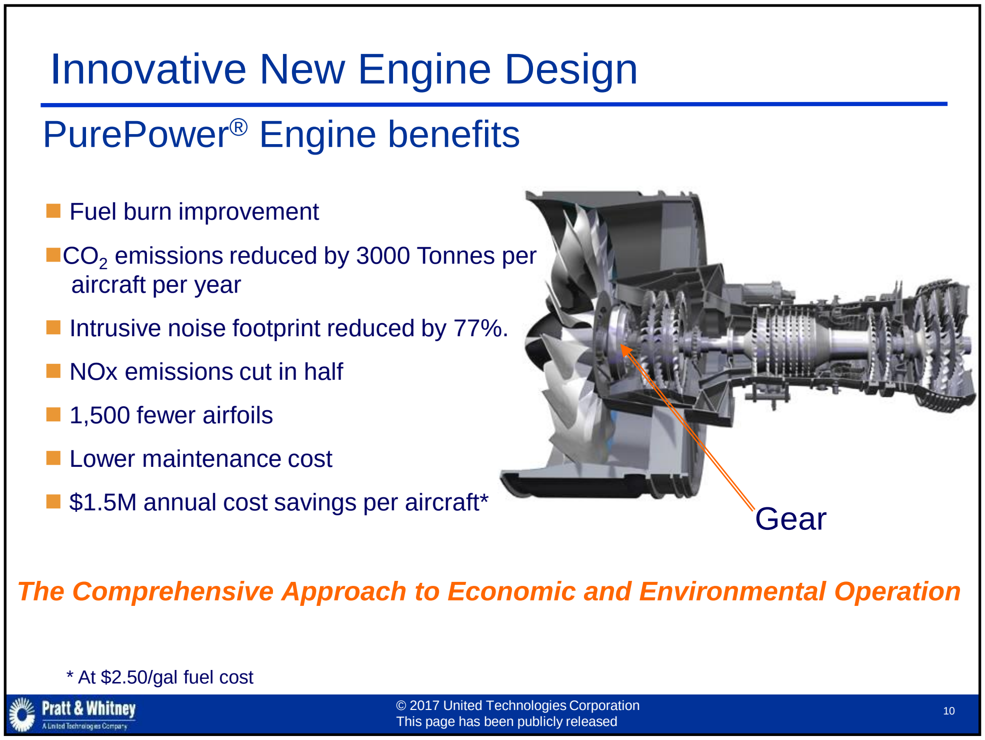

Figure 3.5(a)-3 *Benefits of Geared Turbofan Engine*

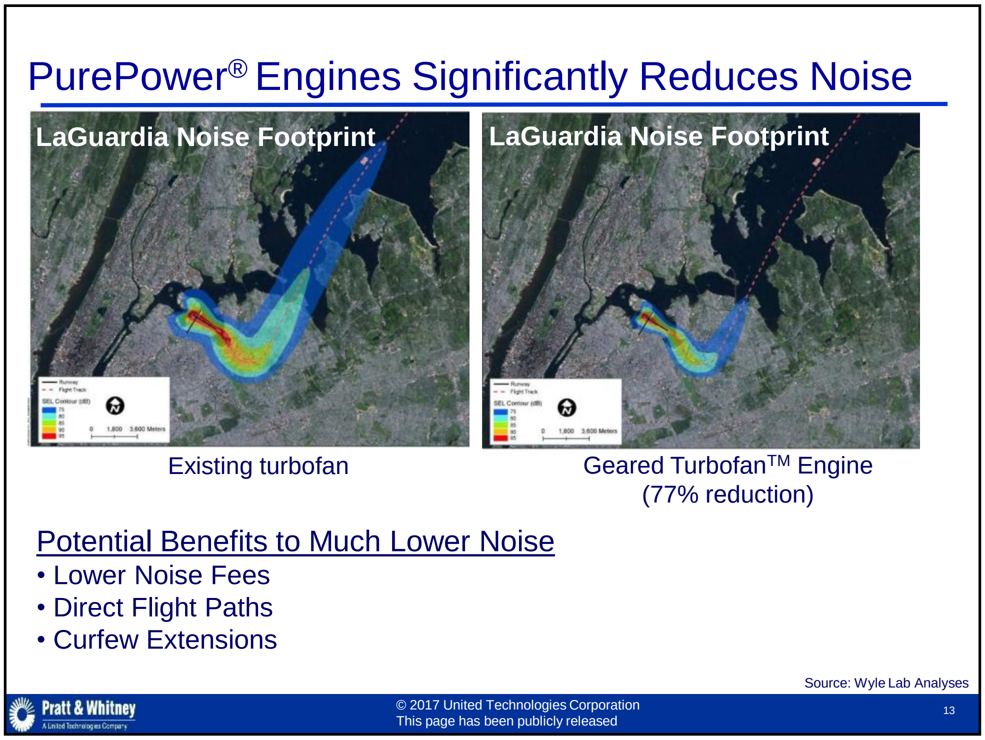

Figure 3.5(a)-4 Aircraft Noise Footprints With and Without Geared Turbofan Engine

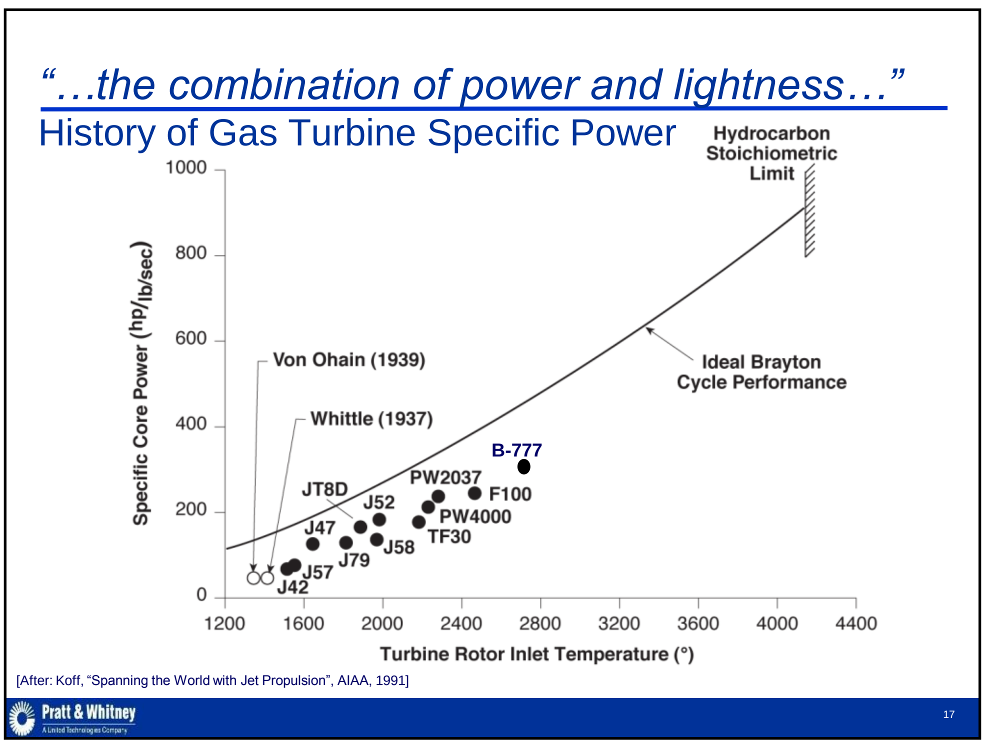

Figure 3.5(a)-5 Advances in Gas Turbine Specific Core Power

3.5(b) Engine Development: The Prospects for Future Engines—Quieter, Cleaner, and Environmentally Protective *(Presenter 2 of 2)*

John Kinney—*GE Aviation*

For decades, General Electric has been a global supplier of commercial, military, business, and general aviation jet engines while providing continuous improvements in flight safety, thrust-to-weight ratio, fuel efficiency, and noise level. When it comes to these types of advances by GE and others, the role of industry/government partnerships should not be underestimated.

John Kinney, GE Aviation's Director, Advanced Technology Business Development, focused his presentation on: "Where are we going with aviation and what is the future of propulsion engines?" He opened by acknowledging the importance of support from, and collaboration with, NASA (formerly the National Advisory Committee for Aeronautics, or NACA) and the FAA. It must be reinforced with our elected officials, Kinney said, how critical public/private partnerships are to continued improvements in aviation noise reduction and efficiency. Industry partnerships with government have been a mainstay of American aviation from its outset, making the U.S. aviation industry the envy of the world.

Safety is the top priority in aviation, which demands that technologies be proven for safety prior to service. Aviation is a long-cycle industry with high development costs and high risk. A continuing strategic vision, with an emphasis on safety as well as other factors such as efficiency, customer needs, and the environment is required during the 15 to 20 years of product development.

Decades of dramatic achievements in aircraft engines are summed up in Figure 3.5(b)-1. Ongoing successes since the industry's early days include thermal efficiency improvements in the gas generator, followed by increased propulsive efficiency with high-bypass ratios that have further reduced both fuel burn and noise. However, Kinney pointed out, "If there ever was an era of low-hanging fruit, that doesn't exist anymore" and it is harder and harder to bring improved products into the market.

Constraints imposed on engine manufacturers are currently much more stringent than in the past, Kinney stressed, reiterating the need for public/private partnerships to help develop immature technologies and placing them into products safely.

Aviation industry trends are summarized in Figure 3.5(b)-2. The markets are expecting new applications to have fuel burn reductions of 15 percent or more, the speaker said. At the same time increasingly stringent requirements are addressing CO_2 and NO_x emissions and community noise. Demands are also substantially increasing for onboard electric power.

The equation shown in Figure 3.5(b)-3, the speaker explained, relates range to design factors such as weight and efficiency that are available to propulsion manufacturers—describing the physics of "readiness to serve." Kinney supports work in the area of thermal efficiency, he went on to say, and his group has been working with highly loaded compressors, in partnership with NASA, to develop very high overall pressure ratio compressors, low-loss inlets, variable loss exhaust systems, and high-bypass ratio turbofans. The team has looked at empty weight and the contributions of materials such as ceramic-matrix composites, polymer-matrix composites, and other materials that help reduce weight in the system. Assessment of these items has contributed to community noise reductions.

The presenter next addressed limitations imposed by the current Brayton Cycle on improvements in thermodynamic efficiency. Figure 3.5(b)-4 shows turbofan thermodynamic trends in the 1960–2050 time frame. The green curve is for wide-body applications and the blue curve is for narrow-body applications. Looking ahead, limits exist on efficiency improvements, Kinney stated—both thermal and propulsive, and for both wide- and narrow-body classes. We must be thinking what will change in the future, according to Kinney: How much more can be done to reduce community noise with conventional systems and architectures?

In the context of opportunity spaces, Figure 3.5(b)-5 addresses two paradigm changes. One relates to unducted fan growth now being demonstrated by GE. Kinney described the "tremendous potential" of unducted propulsors, on which the company worked with the FAA through its CLEEN program and with NASA and its Environmentally Responsible Aviation program. The collaborative efforts demonstrated 26 percent better fuel burn in the state-of-the-art engines and about 17 to 20 EPNdB cumulative reduction in noise compared with Stage 4 requirements. The second paradigm change relates to hybrid electric, which Kinney emphasized does not require batteries.

Regarding changes needed in architecture going forward, the presenter stated that novel propulsor design and novel integration with the airframe are key to achieving step changes related to community noise. Figure 3.5(b)-6 illustrates future design space concepts for advanced propulsion systems and advanced airframes with untapped performance potential. The lower right side of that figure shows the NASA concept for single-aisle turbo-electric aircraft with aft boundary layer propulsion (STARC-ABL). Kinney said that, looking at hybrid bodies or embedded-ducted fans or distributed propulsion, many concepts could improve the efficiency of the system, and also reduce its noise. Studying and developing these systems will require significant investment, again driving home the need for public/private partnerships to ensure safe and otherwise successful results.

The final two slides shown by Kinney, Figure 3.5(b)-7 and Figure 3.5(b)-8, respectively highlight a vision for propulsion system technology of the future—specifically, the 2030–2050 time frame—and a "then and now" look at the first century of flight's 12 HP engine and today's 136,000 HP engine in regular service.

Some people might question the need for change, stating the status quo is better and more efficient. Kinney responds that we must move from the Brayton Cycle to some new technology of the future. "We've got to do that," he stated in his concluding remarks, "and we've got the potential for doing that."

Continuing challenges must be addressed as a society, Kinney said. "I want lower noise. I want better efficiency. I want lower environmental impacts." To achieve these outcomes, "We have to be willing to take big steps," he said. Public/private partnerships, the speaker concluded, are "making these impossible dreams into possible realities."

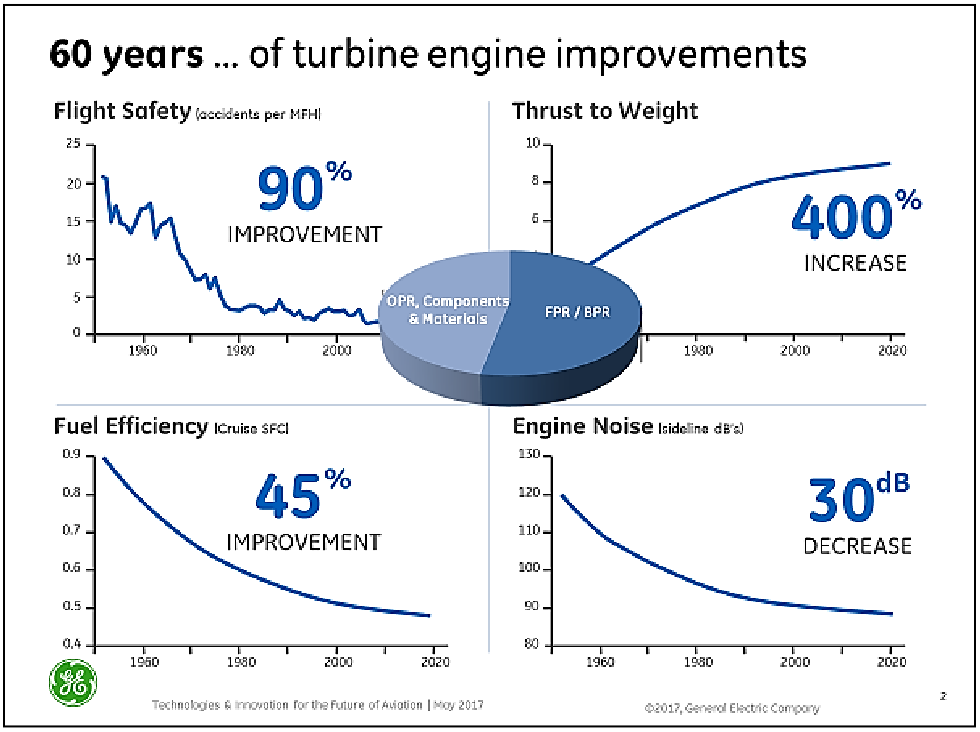

Figure 3.5(b)-1 Turbine Engine Improvements Spanning Decades

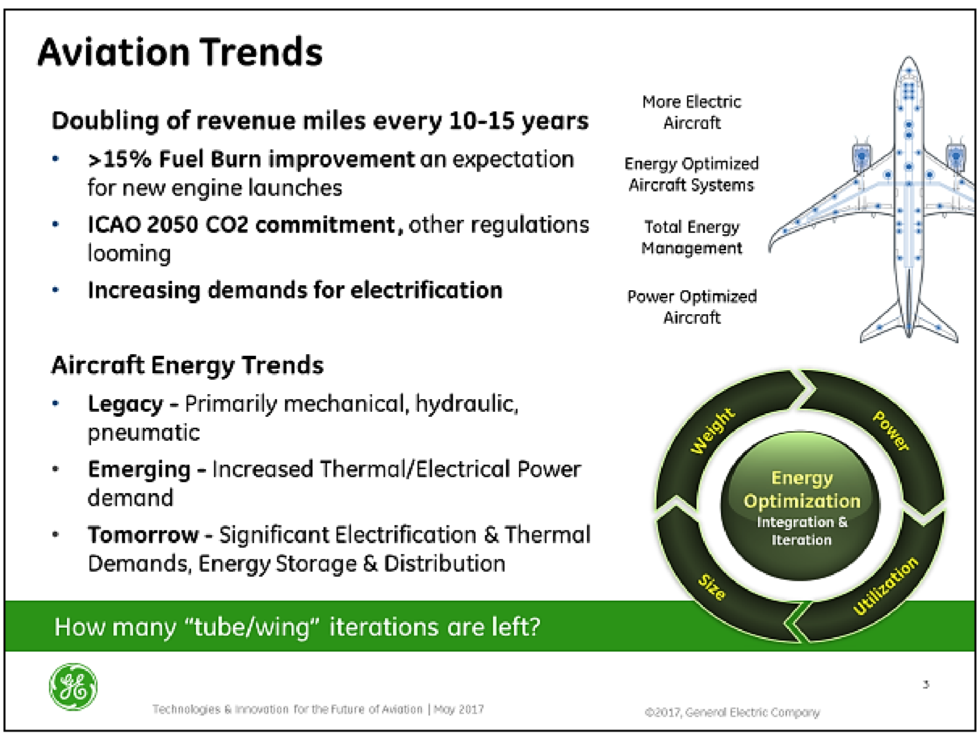

Figure 3.5(b)-2 Trends in the Aviation Industry

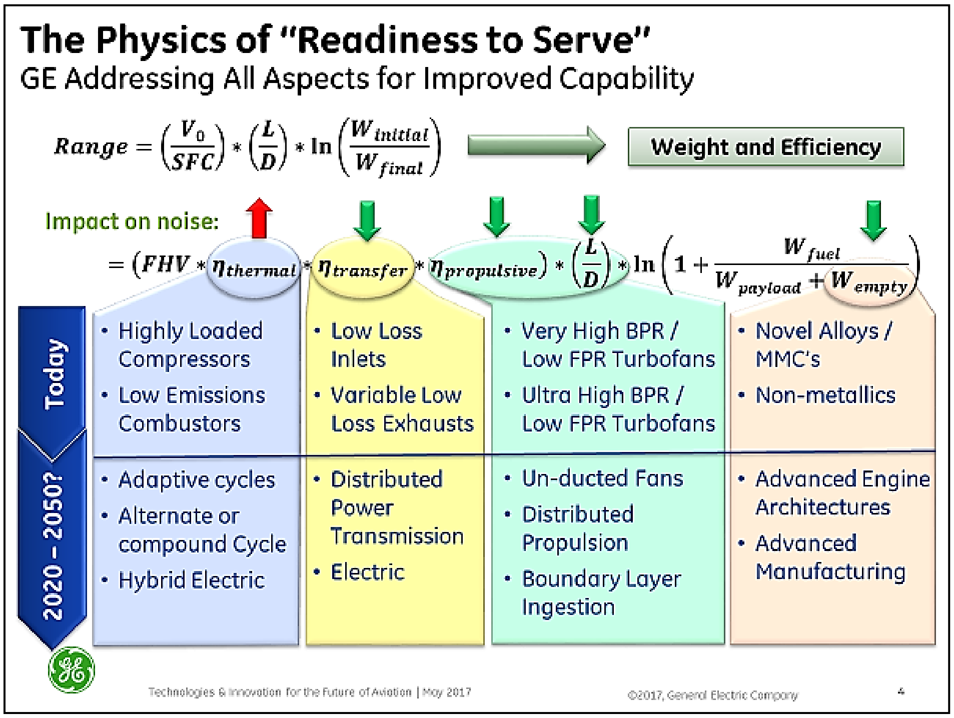

Figure 3.5(b)-3 *Range Related to Engine Design Factors*

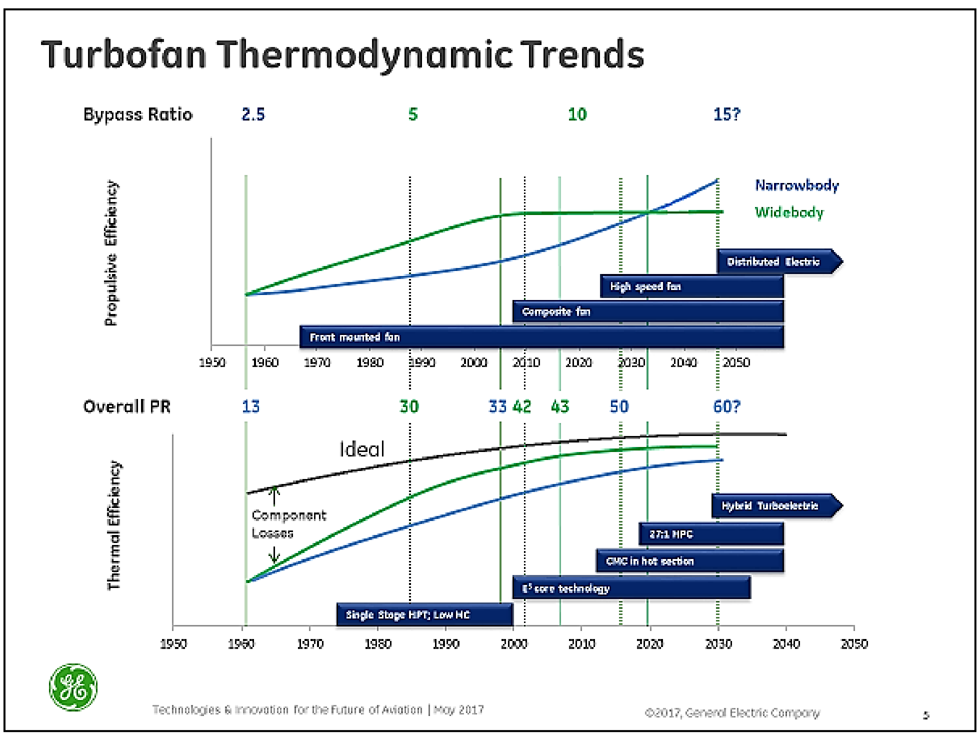

Figure 3.5(b)-4 *Turbofan Thermodynamic Trends, 1960–2050*

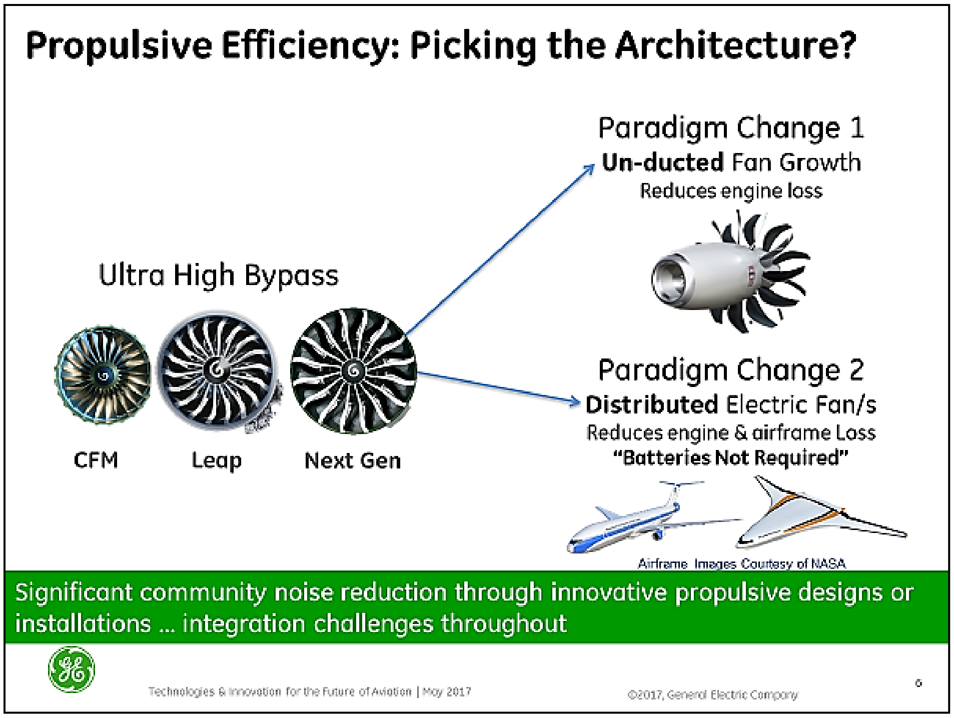

Figure 3.5(b)-5 Propulsor Opportunity Spaces

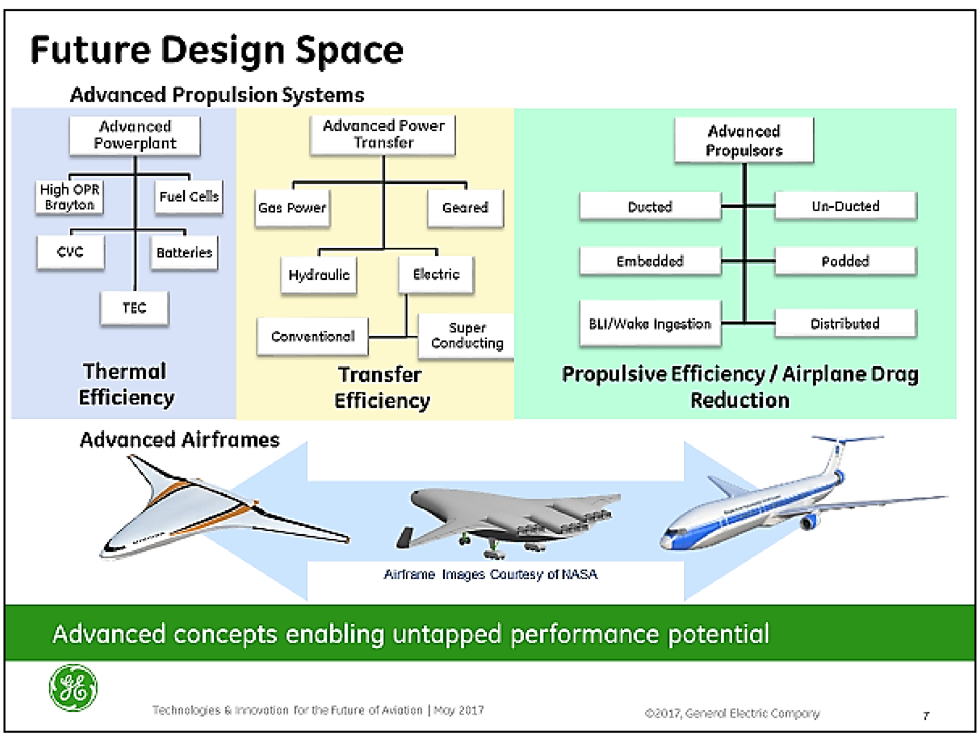

Figure 3.5(b)-6 Advanced Propulsion and Airframe Design Space

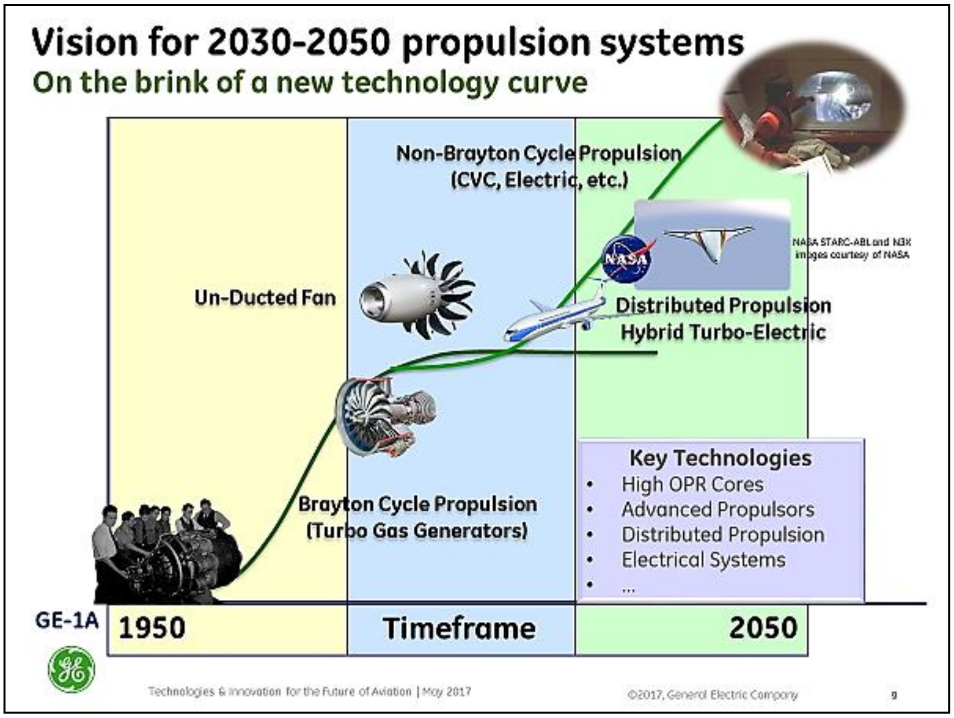

Figure 3.5(b)-7 *Propulsion Systems—Visions for the Future*

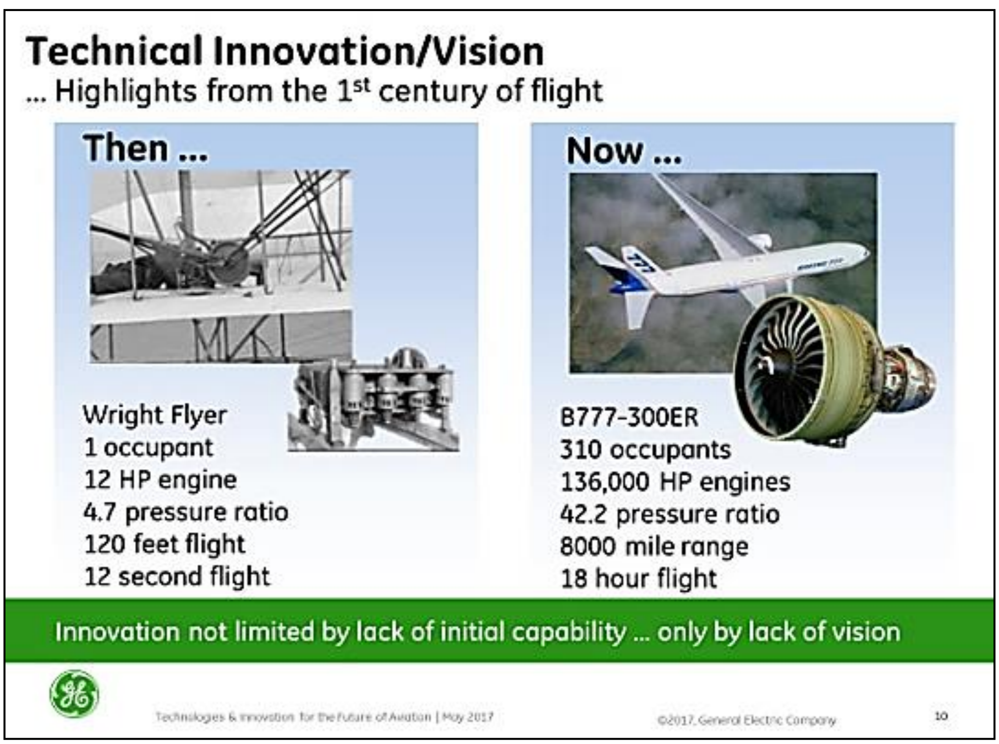

Figure 3.5(b)-8 *Technology Innovation for Aircraft Engines, Then and Now*

3.6 Airplane Design: Possibilities for the Future

3.6(a) Airplane Design: Possibilities for the Future
(Presenter 1 of 2)

Brian Yutko—Aurora Flight Sciences

Designed as an ultra-efficient subsonic transport aircraft, the D8 commercial aircraft in development promises dramatic reductions in noise, along with gains in fuel efficiency. The potential payoffs from the D8 concept accrue from features such as its integrated airframe, propulsion for boundary layer ingestion, and "Double Bubble" design that moves the engines from the wings to the back of the fuselage, helping to shield the engine noise from observers on the ground. The D8 concept meanwhile has technical risks associated with it, and its development has relied on innovative research made possible by public-private collaboration.

Brian Yutko, with Aurora Flight Sciences, provided an overview of the D8 commercial aircraft concept and its associated noise abatement potential. Figure 3.6(a)-1 summarizes the history of the D8 concept plane, designed as an ultra-efficient subsonic transport aircraft. Answering to the NASA goals for industry under its N+3 program, Aurora teamed up with MIT and Pratt & Whitney to develop the D8 concept. In addition to this further-term design development, Yutko also works with MIT – including with workshop presenter Professor John Hansman – on near-term, operational noise mitigations.

The D8 concept is shown in Figure 3.6(a)-2, which highlights its main features: integrated airframe, propulsion for boundary layer ingestion (BLI), and "Double Bubble" design that takes the engines off the wings and integrates them into the back of the fuselage, helping to shield the engine noise from observers on the ground. The D8, presenter Yutko said, "is one of the aircraft concepts that may provide a step change in noise performance going forward."

Noise benefits are gained from the engine shielding, while fuel benefits come from the boundary layer ingestion. The Double Bubble composite fuselage has an elliptical shape, providing greater fuselage lift when compared with a traditional, nearly-round fuselage (although not quite to the extent achieved by a blended-wing body) and introducing design possibilities such as shrinking the wings and tail.

Figure 3.6(a)-3 shows the features of both the current product trends as well as the conceived method of propulsion system improvement. "Essentially, what's been done with the latest generation of engine products," Yutko stated, "is you're taking a large amount of air and you're moving it slowly versus taking a small amount of air and moving it quickly." In doing so, jet losses are reduced and propulsion efficiency is increased. Another approach, he said, is to integrate the propulsor into the boundary layer created by the fuselage and consume that boundary layer, which has its own benefits and challenges.

From an operations standpoint, the D8 concept allows for "a twin-aisle aircraft that's designed for the single-aisle market," the presenter said. This benefit requires a novel, weight-efficient structural arrangement to compensate for the fact that an elliptical shape is not an ideal pressure vessel, explained Yutko, whose team is working with the FAA toward ground test demonstrations to prove out the performance of a certifiable composite structure that enables two aisles.

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Turning the focus to the D8's noise performance, Yutko spoke of the "2016 D8" concept with engine technology and materials used in current aircraft. The speaker's team has also worked with NASA on technology for midterm variance that is still under development. Yutko showed Figure 3.6(a)-4 that summarizes D8 metrics related to noise emissions, as well as fuel consumption—specifically, a 32 dB cumulative noise benefit below Stage 4 and about a 60 percent fuel burn benefit is estimated for the mid-term 2030/2035 time frame.

Next, the speaker showed a comparison of a current noise contour for a 737-800, the so-called 2016 D8, and the D8 technology in development by NASA for the longer term. See Figure 3.6(a)-5 that presents aircraft approach noise contours using the L_{max} metric. "You can see a pretty significant reduction in the 65 dB L_{max} contour," Yutko pointed out. The speaker showed noise contours at airports that likewise showed noise reductions coming with evolutions in D8 aircraft technology. Figure 3.6(a)-6, which depicts population exposure for approaches on a LAX runway, shows about 160,000 fewer people exposed to 60 dB L_{max} with year 2035 D8 technology compared to current 737-800 technology.

Yutko reiterated the belief expressed by previous presenters that looking at 65 DNL is not enough, saying that lower noise levels, and perhaps alternative metrics, as well, must be considered. Complaints are received largely starting at the 55 DNL contour level. The speaker next went over assessments of noise exposed population for the busiest 20 U.S. airports comparing current aircraft and 2035 D8s. He pointed out a 31 percent reduction in population (2,000,000 fewer people) exposed to 55 DNL or greater, a 56 percent reduction in population (1,000,000 fewer people) exposed to 60 DNL or greater, and a 77 percent reduction in population (300,000 fewer people) exposed to 65 DNL or greater. "So the advanced concepts have a pretty significant potential to actually make that step change in noise performance," Yutko stated, stressing that concepts are of course subject to risks such as technical, financial, and market risks.

The presenter spoke briefly about technical risks associated with the D8, explaining these break down into Double Bubble airframe-related risks, boundary layer ingestion-related risks in terms of engine operability and fan performance, and integration risks that require coordination between engine and airframe manufacturers.

On airframe-related risks, Yutko's team is working with the FAA to demonstrate efficient solutions for creating an elliptical fuselage, which promises noise as well as fuel benefits. The Y-joint at the bottom of the Double Bubble is made from 3D woven composite pre-forms, and will be created on an automated fiber placement machine in a production environment. See Figure 3.6(a)-7.

Referring to Figure 3.6(a)-8, Yutko spoke of an aircraft with engines on the wings that will be at Technology Readiness Level (TRL) 5 this year, and will be demonstrated as part of the CLEEN program. By 2021, he expects to have an X-plane prepared to fly TRL 7. As depicted in Figure 3.6(a)-9, the X-plane is approximately a 52-percent version of the full-scale aircraft and will demonstrate both the composite fuselage technology and propulsion system technology.

Yutko concluded his presentation speaking about public-private partnerships and the decreased risk and increased investment—as well as out-of-the-box thinking—made possible by government support for industry and academic efforts. Yutko said that public-private partnerships are required for the development of advanced, lower TRLs which will then enable revolutionary changes.

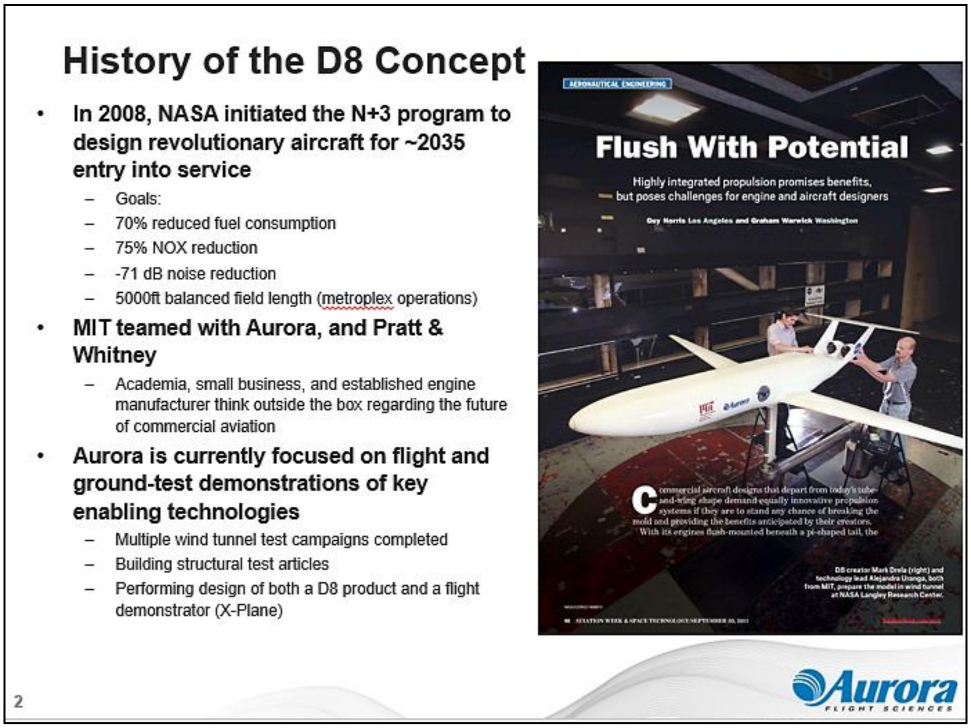
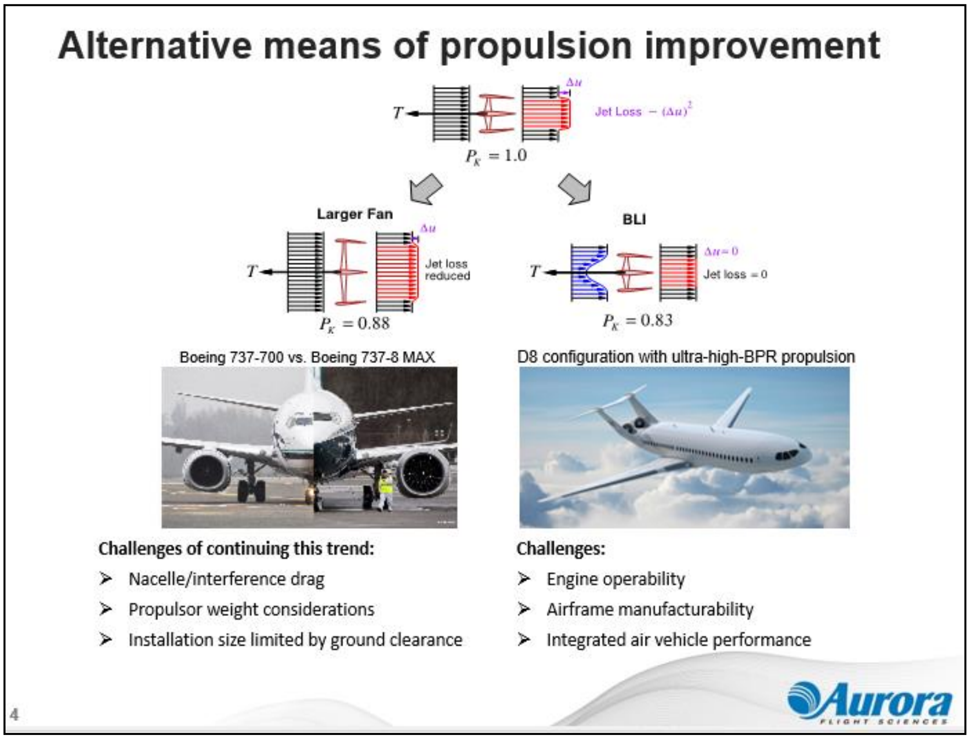


Figure 3.6(a)-1 *D8 History*

Figure 3.6(a)-2 *A Look at D8 Design Basics*



(BPR refers to turbine bypass ratio)

Figure 3.6(a)-3 *D8 Propulsion: Design Challenges*

NASA Subsonic Transport System Level Metrics (STSLM) Summary Table

Technology Benefit	NASA Mid Term Goals	2016 D8	Mid Term D8
Noise (cum below Stage 4)	32-42 dB	21 dB	32 dB
LTO NOx Emissions (below CAEP 6)	80%	50%	77%
Cruise NOx Emissions (rel. to 2005 best in class)	80%	50%	73%
Aircraft Fuel/Energy Consumption (rel. to 2005 best in class)	50-60%	29%	61%

D8 concepts not optimized for noise;
Further multi-objective optimization possible
Performance evaluated on 900nmi mission

9

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Figure 3.6(a)-4 *Metrics: Noise, Emissions, Fuel Consumption*

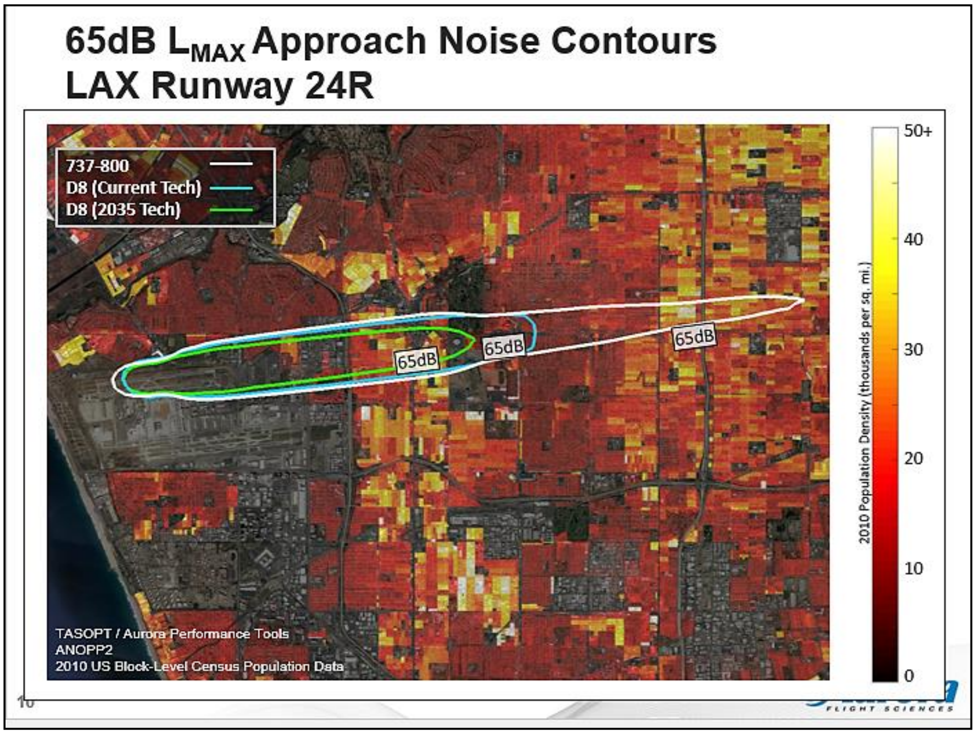


Figure 3.6(a)-5 *Approach Noise Contour Comparison at LAX Runway 24R*

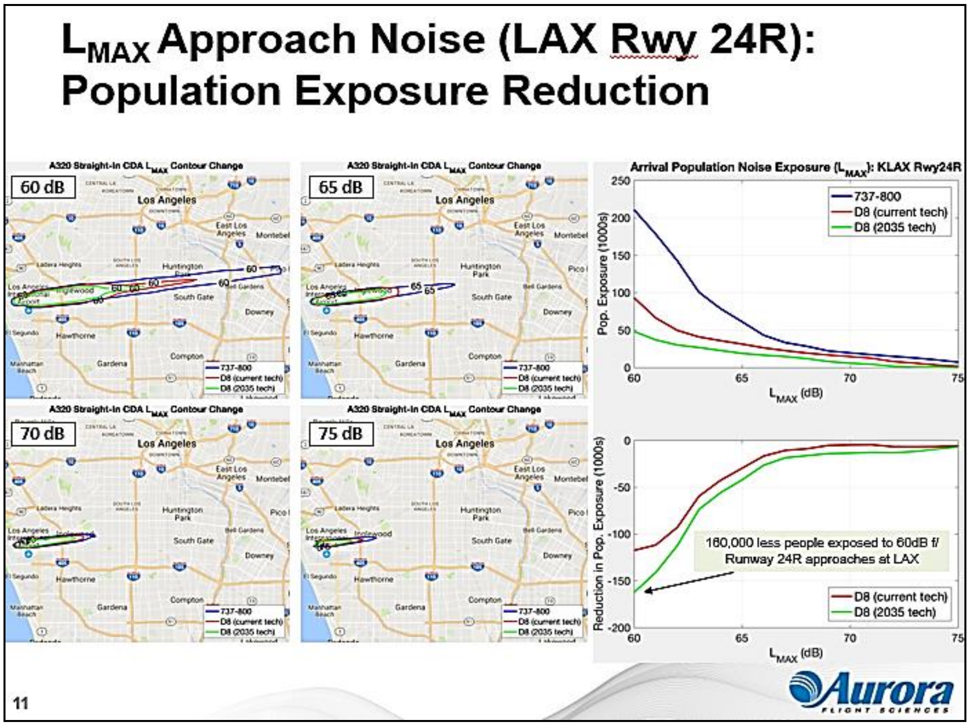


Figure 3.6(a)-6 *Approach Noise Exposure Reduction at LAX Runway 24R*

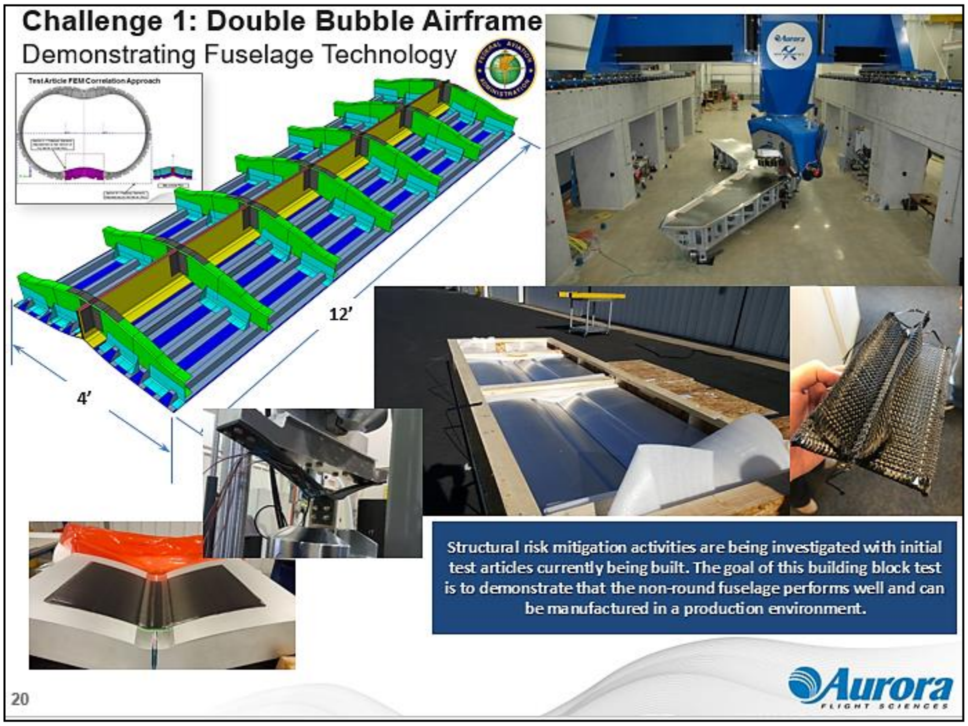


Figure 3.6(a)-7 *Double Bubble Airframe Challenge*

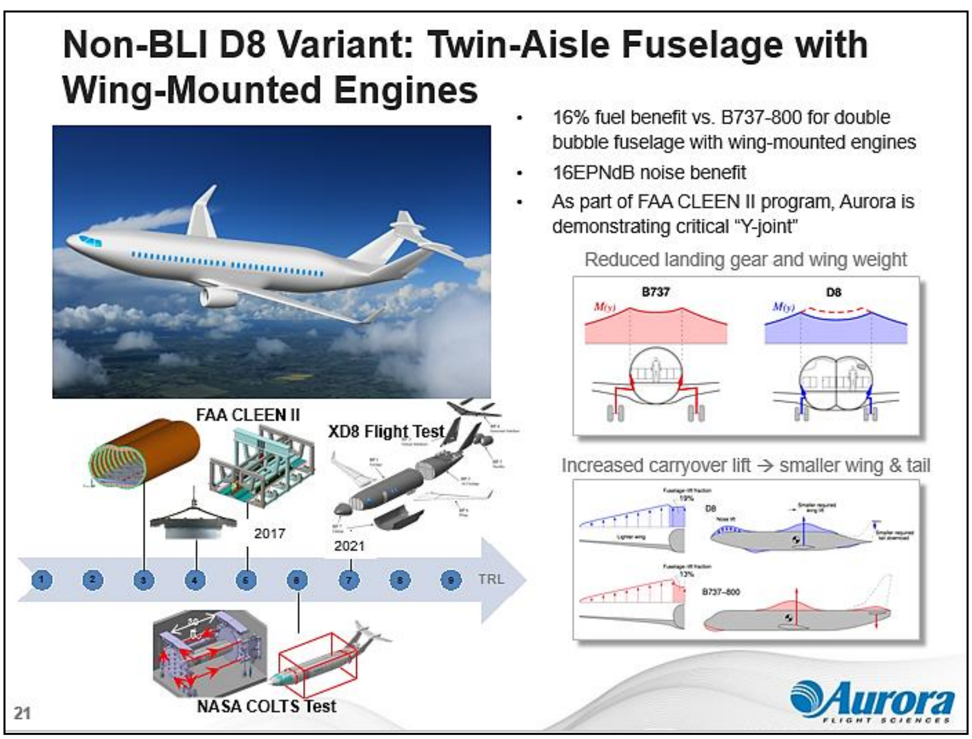


Figure 3.6(a)-8 *D8 Design With Engines on the Wings*

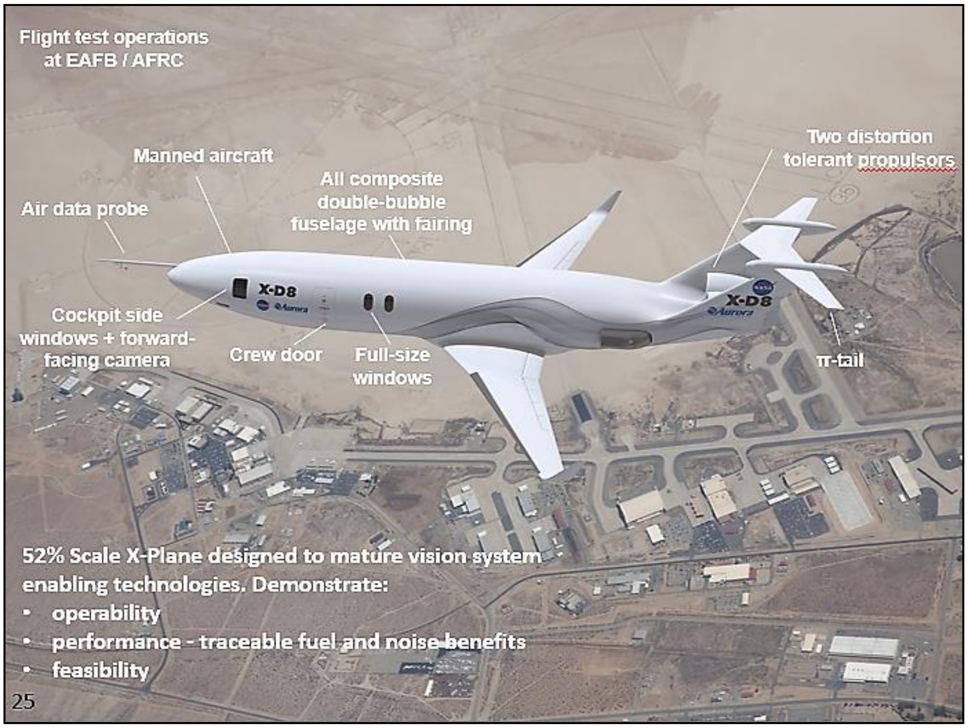


Figure 3.6(a)-9 *X-Plane to Demonstrate Composite Fuselage, Propulsion System Technology*

3.6(b) Airplane Design: Possibilities for the Future

(Presenter 2 of 2)

Mark Page—*DZYNE Technologies*

The search is on for the aircraft of the future, and the Ascent 1000 is one example of an aircraft design concept that, by its innovative blended wing design, promises marked improvements in both fuel efficiency and noise. One significant advantage of the aircraft's innovative design: a lift-to-drag ratio that sets it apart from traditional aircraft. Aircraft noise predictions are auspicious, and the X-plane program offers the opportunity to demonstrate the expected advantages of this avant-garde configuration.

Mark Page, DZYNE Technologies Vice President and Chief Scientist, presented his industry perspective on the aircraft of the future. His company is pursuing an innovative Ascent 1000, which has noise benefits that Page addressed after discussing other aspects related to airplane design and fuel efficiency.

The Ascent 1000 is characterized by a blended wing design that provides an impressively efficient lift-to-drag ratio through more span and less friction. Rearranging the basic tube-and-wing characteristics in various ways, as described in Figure 3.6(b)-1, achieves the significant advantages that, all told, increase the lift to drag by 30 percent.

DZYNE Technologies' "disruptive attack" underway will start at the regional jet size, Page explained, with the intent of getting the technology into service once developed. This is the company's entry point into the single-aisle market, "where we'll have the best benefit to the world," the presenter said, explaining the company plans to start small and grow big, to a capacity of about 260 passengers for its basic airplane.

Page introduced his company's so-called "Vision System" for the NASA X-plane program. The Ascent 1000 aircraft, overviewed in Figure 3.6(b)-2, weighs slightly over 100,000 pounds as a transport—a super regional with 112 passengers—and with slightly less weight as a business jet (aka, "BizJet"). The interior, Page said, shares the pressure-tension ribs of the D8 discussed by the previous presenter, Dr. Brian Yutko.

DZYNE was working to optimize its aircraft's fuel burn as a BizJet, then shifted its priorities to add floor area into a design that would meanwhile require less take-off and landing field length. Figure 3.6(b)-3 compares the Ascent 1000 Vision System with the ERJ-190 aircraft, revealing the promise of a 60 percent fuel burn reduction and an 86 percent NO_x emissions reduction (thanks in large part to the Geared Turbofan (GTF) engine, Page explained).

These estimates are based on no hybrid laminar flow and no riblets or similar technologies, Page pointed out. And the airplane is not boundary layer ingesting, the speaker stressed, although it could easily be converted if engine companies developed tolerant, cost-effective fans to support this change. Comparing the BizJet concept's gross weight with that of a regional jet, which would be filled with people flying within a much shorter range and with the need for much less fuel, the aircraft designers found them comparable, a result Page described as "very exciting."

Page discussed the Ascent 1000's noise characteristics next, highlighting the aircraft's "very substantial" noise benefit that outperformed the NASA N+2 threshold by some 7 dB and very nearly approached the NASA N+2 objective.

The Ascent 1000 noise reduction is primarily attributable to:

- Forward radiated fan noise that is strongly shielded
- Jet noise that is partially shielded
- Noise from the smaller nose and main gear that is reflected downward
- The lack of slat or flap noise.

The Ascent 1000's lift-to-drag ratio is twice that of a traditional airplane on takeoff. This results in the Ascent 1000 being higher above certification microphones than traditional aircraft as reflected in Figure 3.6(b)-4. An analysis conducted by Georgia Tech using the Aircraft Noise Prediction Program (ANOPP) from NASA provides the cutback, sideline, approach, and cumulative noise predictions shown in Figure 3.6(b)-5. The 39.5 EPNdB cumulative noise benefit is "extraordinary," Page stated.

The X-plane program provides the opportunity to demonstrate and validate the range of potential advantages offered by the DZYNE aircraft, with its technologies that are continually being optimized. DZYNE will be demonstrating basic blended wing design aerodynamics for low fuel consumption, and at the same time a low acoustic signature. "First by reducing the energy put into the air by reducing the size of the airplane, but then in addition getting shielding benefits—tremendous," said the presenter.

Page's company is developing an airplane proposal that, from a business standpoint, could break into the marketplace. The challenge, Page said in conclusion, is to compete with the incumbent programs of companies like Airbus and Boeing and in particular their successful, rooted designs such as the 737 and A320.

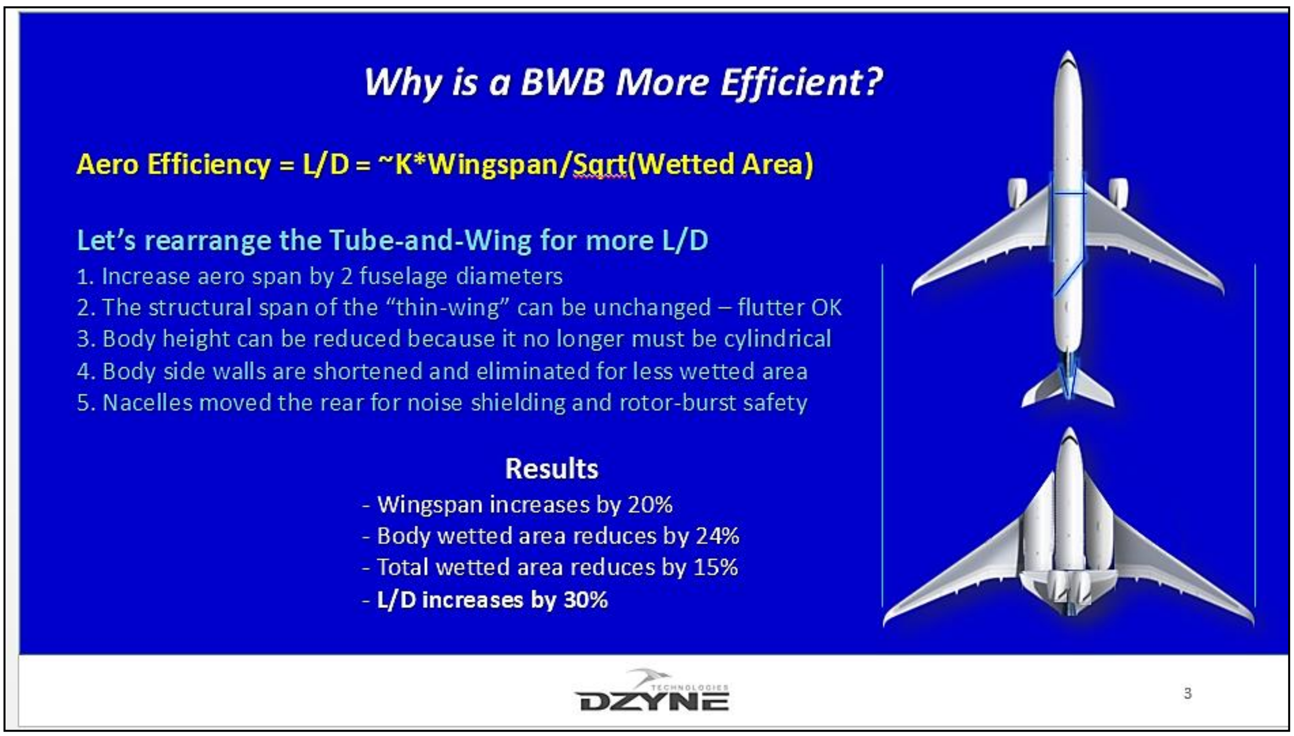


Figure 3.6(b)-1 *Advantages of a Blended Wing Body*

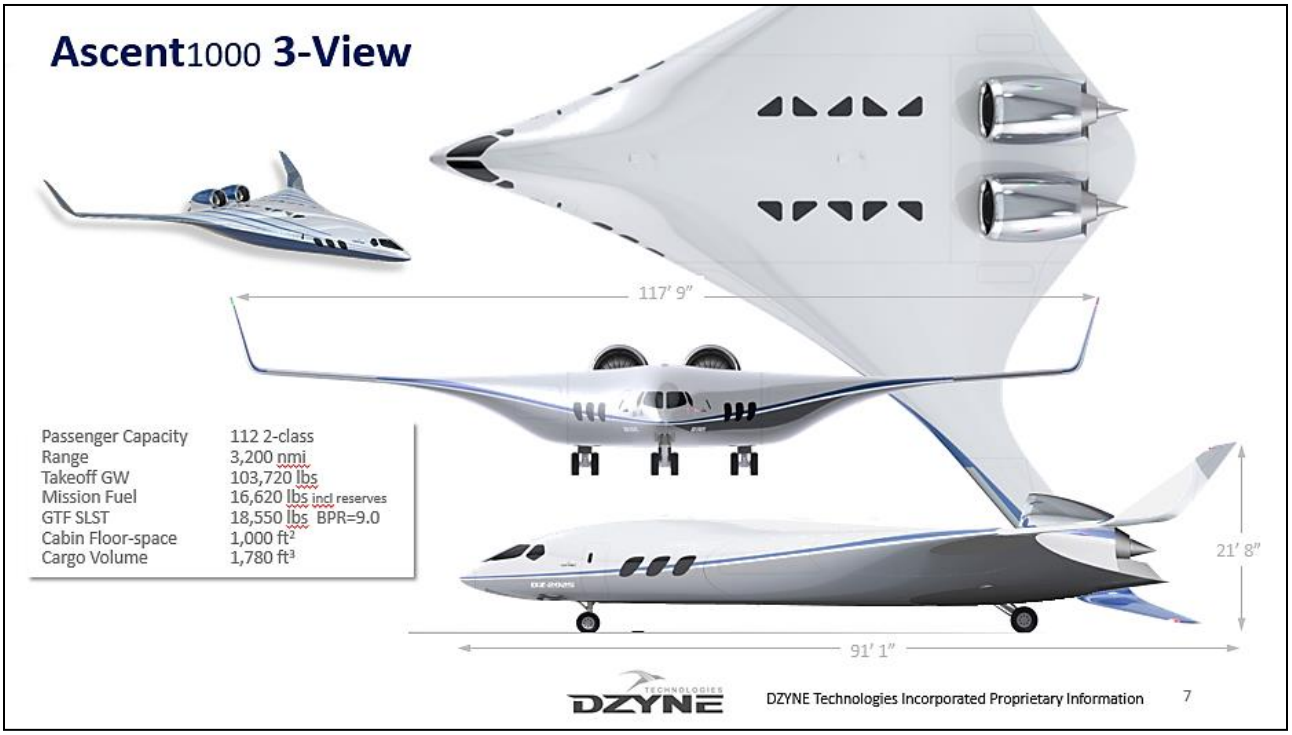
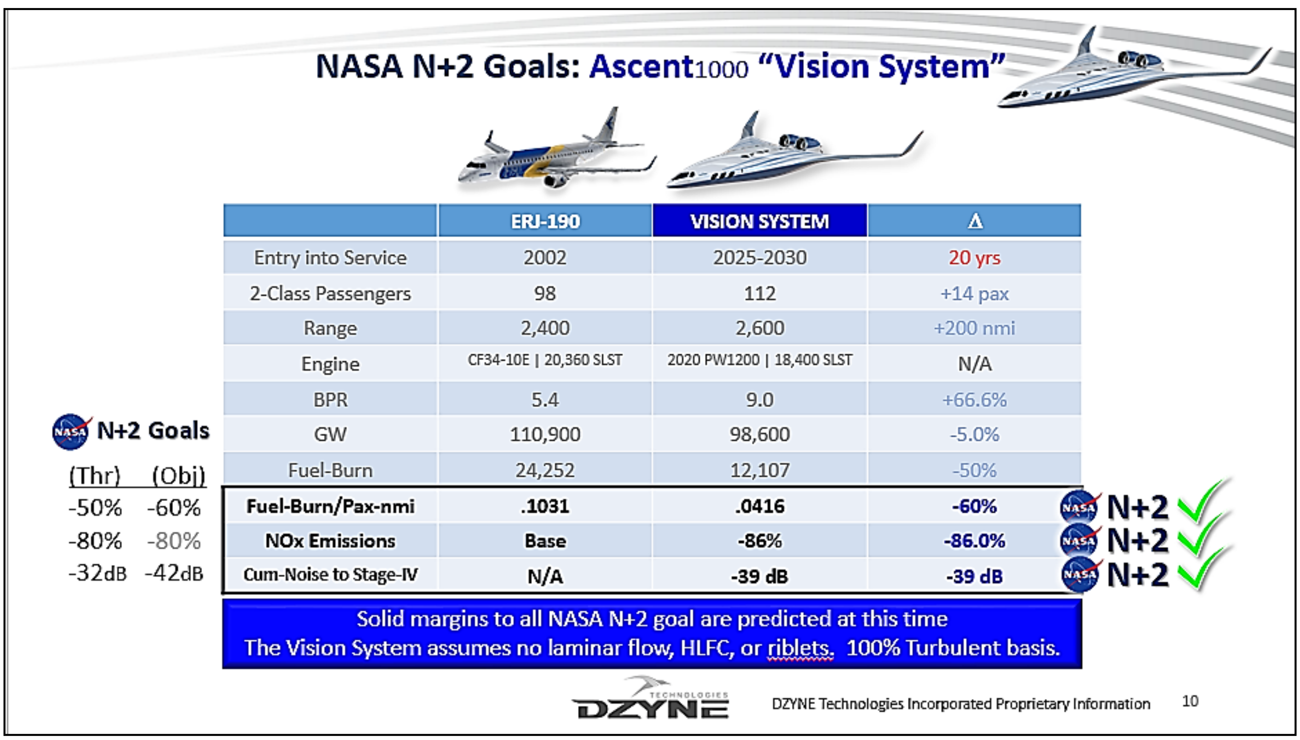


Figure 3.6(b)-2 *Overview of the Ascent 1000*



	ERJ-190	VISION SYSTEM	Δ
Entry into Service	2002	2025-2030	20 yrs
2-Class Passengers	98	112	+14 pax
Range	2,400	2,600	+200 nmi
Engine	CF34-10E | 20,360 SLST	2020 PW1200 | 18,400 SLST	N/A
BPR	5.4	9.0	+66.6%
GW	110,900	98,600	-5.0%
Fuel-Burn	24,252	12,107	-50%
Fuel-Burn/Pax-nmi	**.1031**	**.0416**	**-60%**
NOx Emissions	**Base**	**-86%**	**-86.0%**
Cum-Noise to Stage-IV	**N/A**	**-39 dB**	**-39 dB**

Figure 3.6(b)-3 *Ascent 1000 Versus ERJ-190 (Current technology Regional Jet benchmark selected by NASA)*

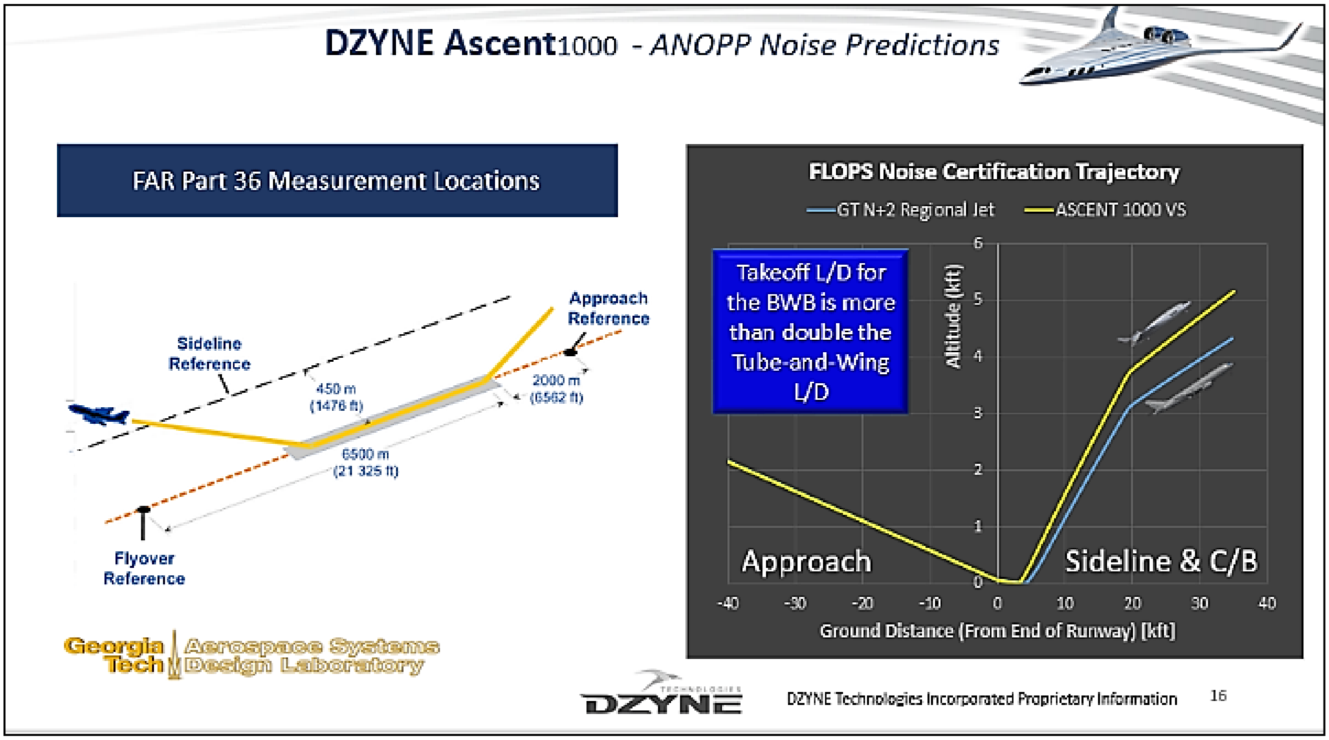


Figure 3.6(b)-4   Measurement Locations, Lift-to-Drag Benefits to Noise Reduction

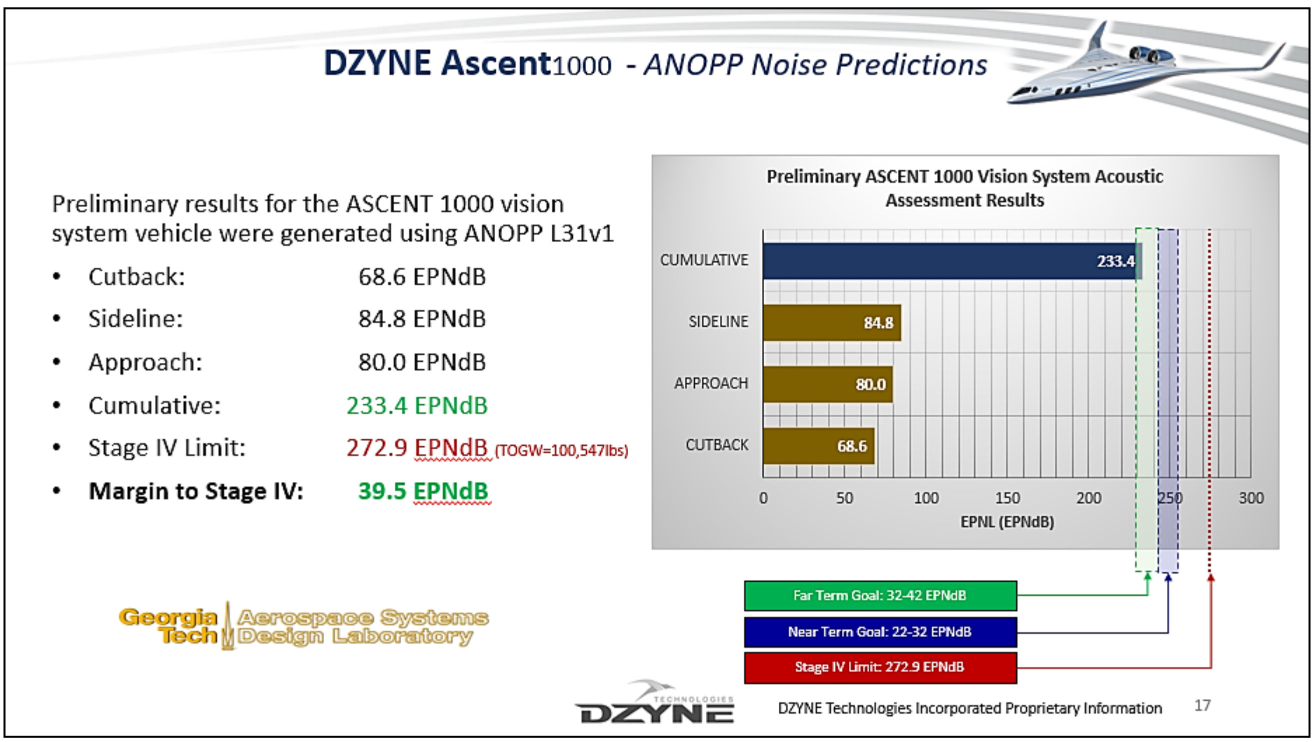


Figure 3.6(b)-5 ANOPP Results for the Ascent 1000

3.7 A Roadmap for European Aeronautics to 2050

Giuseppe Pagnano—*Clean Sky Joint Undertaking*

Noise at airports represents a major issue, along with local air quality, for sustainable air traffic growth, and Europe has made great strides in recent decades in researching and reducing both aviation-related noise and emissions. Clean Sky is one important program contributing to the European effort to reduce aviation noise globally, through direct funding, promotion of related activities, and active collaboration with other international programs including additional European initiatives.

Giuseppe Pagnano, from the European Union research program "Clean Sky Joint Undertaking" presented the European perspective on aeronautics and aviation-associated noise. His presentation focused on what has been accomplished in Europe over the last couple of decades, especially with European Commission cooperative project funding, and about noise-related and other goals of the aviation sector moving forward.

Pagnano introduced the framework of the European Commission's aeronautics efforts. The Clean Sky initiative (which had a budget for noise reduction efforts of €100 million for the first "Clean Sky 1" phase and €103 million for "Clean Sky 2") is part of the European platform known as ACARE (which stands for Advisory Council for Aeronautics Research in Europe). ACARE's "Vision for 2020" defined year 2020 targets for environmental impacts for emissions and noise, and the associated X-Noise initiative is among the projects designed to help achieve noise-associated targets. The recent update of the "Vision" program, called Flightpath 2050, defines targets in the medium term (by the year 2035) and the long term (2050).

Goals for both 2020 and 2050, using comparison to the same 2020 reference year, are presented in Figure 3.7-1. The noise goal went from 50 percent in 2020 to 65 percent reduction in 2050. Vision 2020 noise targets and specific actions to reach these goals are summed up in Figure 3.7-2. Reducing perceived noise, for example, will be accomplished by reduction in per-operation noise of -10 EPNdB, as well as by reduction in the area within which people are affected. Intervention areas to achieve a 65 percent reduction in noise by 2050 are presented in the same figure: The target is expected to be achieved by three types of actions, summarized in basic terms as novel technologies (noise at source), low-noise operational procedures (noise abatement), and better community impact assessment tools (noise annoyance).

Figures 3.7-3 and 3.7-4 present X-noise accomplishments and projections (1998-2020 and 2010-2050 time frames, respectively).

Figure 3.7-5 presents some European Commission-funded "success stories" from Clean Sky and other collaborative projects. Both engine advances and aircraft noise improvements have been made, with advances in areas such as business jet ("BizJet") configurations, helicopter noise abatement, and airport noise assessment. One specific capability highlighted by the presenter: the Technology Evaluator program, which assesses future aircraft's actual expected benefits in terms of emissions and noise.

Clean Sky-funded projects have included flight testing of a full-scale technology demonstrator that included an acoustic liner on the lip with nacelle anti-ice capability; an engine platform project dedicated to large three-shaft engines, testing composite fan systems and other improvements aimed at noise reduction; an early project considered a “flagship” of the Clean Sky program, a contra-rotating open rotor; U-tail shielding on BizJets; and IFR and VFR helicopter noise abatement procedure demonstrations. Pagnano also mentioned that the Clean Sky Technology Evaluator was also used to evaluate noise status at European airports.

After mentioning the 2014 EU Council Regulation establishing Clean Sky 2, Pagnano summarized planned activities related to 2020 and 2035, as listed in Figure 3.7-6, and mentioned the ACARE noise technology goals as captured in Figure 3.7-7.

In an overview winding down his presentation, Pagnano emphasized that safety is priority one. At the same time while primary attention is paid to safety, the noise signature must also be improved, he said. Europe has a “good track record” where noise at source and noise abatement procedures are concerned, the speaker stated, but noise annoyance aspects need additional consideration. Pagnano expressed that European noise efforts must be enhanced for additional active collaboration between the Clean Sky Joint Undertaking and the Single European Sky ATM Research Program, the European Aviation Safety Agency, and other international initiatives. The speaker concluded by presenting additional information about Clean Sky 1 and 2. He briefly discussed funding, major metrics including EPNdB and L_{den}, technological domains related to the Green Regional Aircraft ITD, and progress in CROR aerodynamics and acoustics. For additional information, Pagnano directed people to www.cleansky.eu. (Editorial note: See also [www.cleansky.eu/clean-sky-2-budget] which indicates the EU with a 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).)

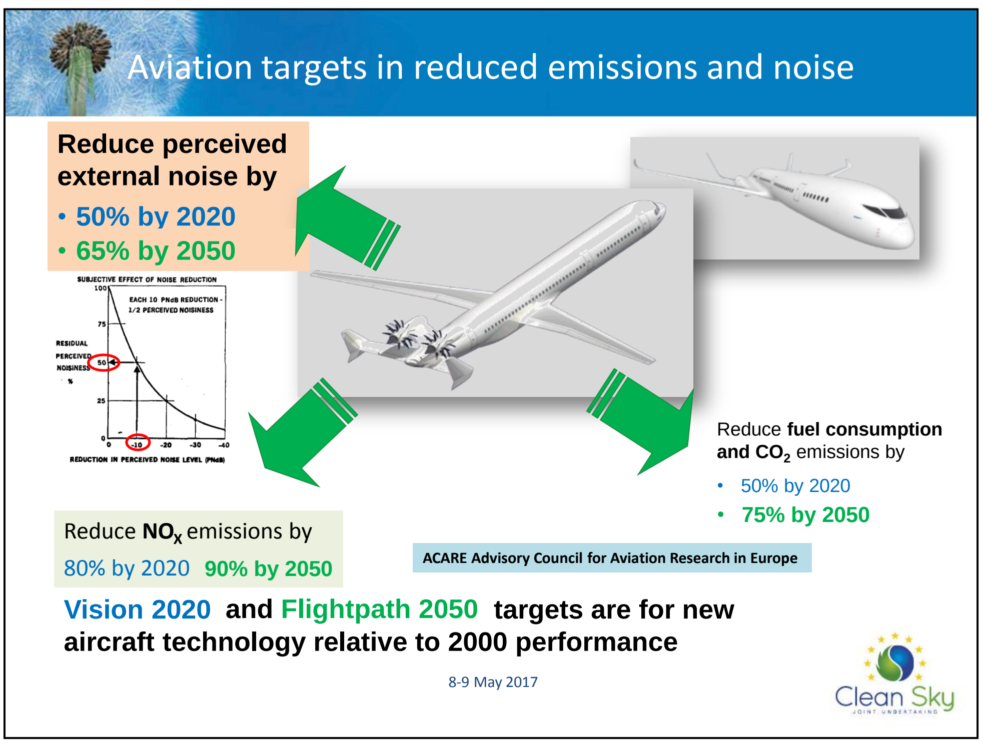


Figure 3.7-1 *Aviation Targets: Reducing Noise and Emissions*

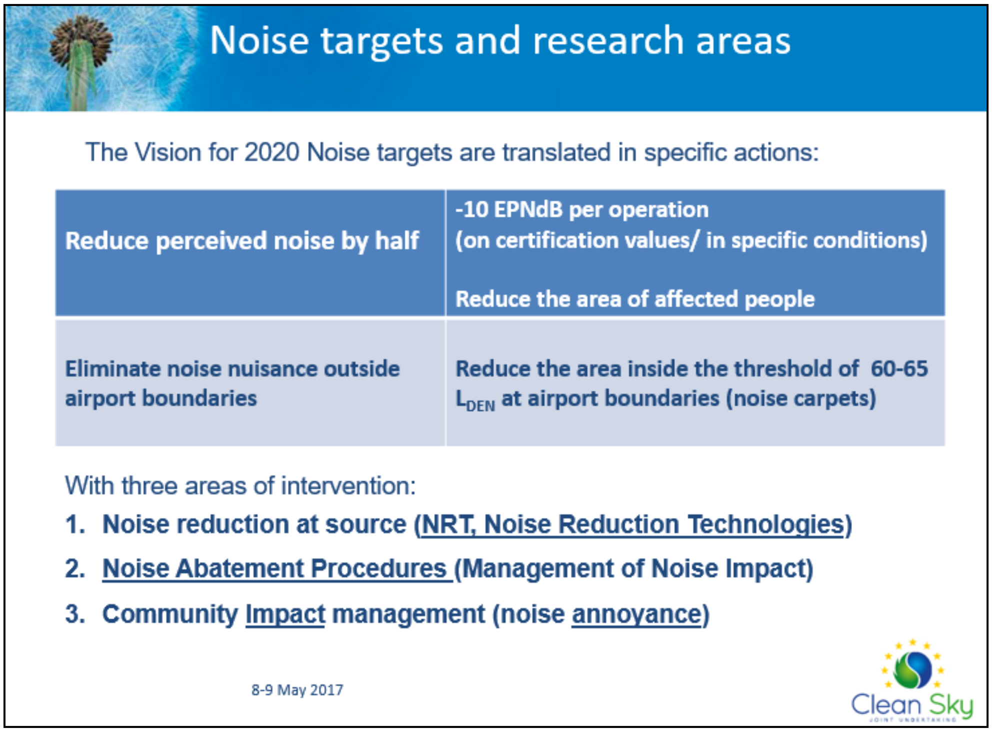


Figure 3.7-2 *Actions Toward Achieving Vision 2020 Noise Targets*

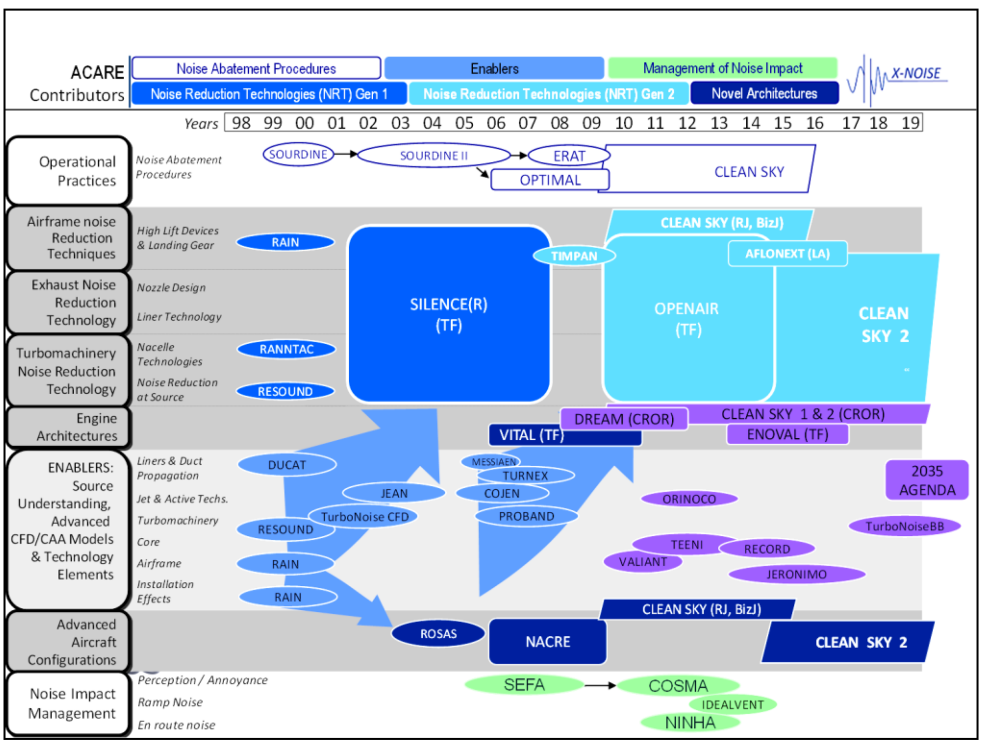


Figure 3.7-3 *A Two-Decade View of Noise Accomplishments*

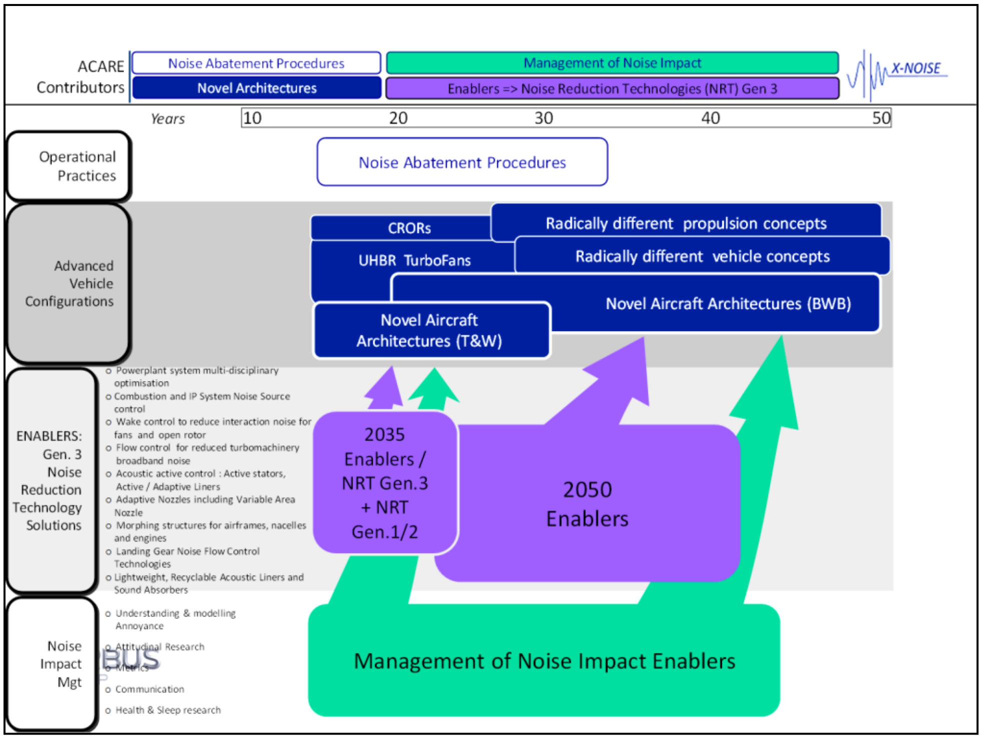


Figure 3.7-4 *2010–2050 Noise Accomplishments, Projections*

Figure 3.7-5 *Successful Research Out of EU Aviation*

Figure 3.7-6   Examples of Planned Noise Reduction Projects

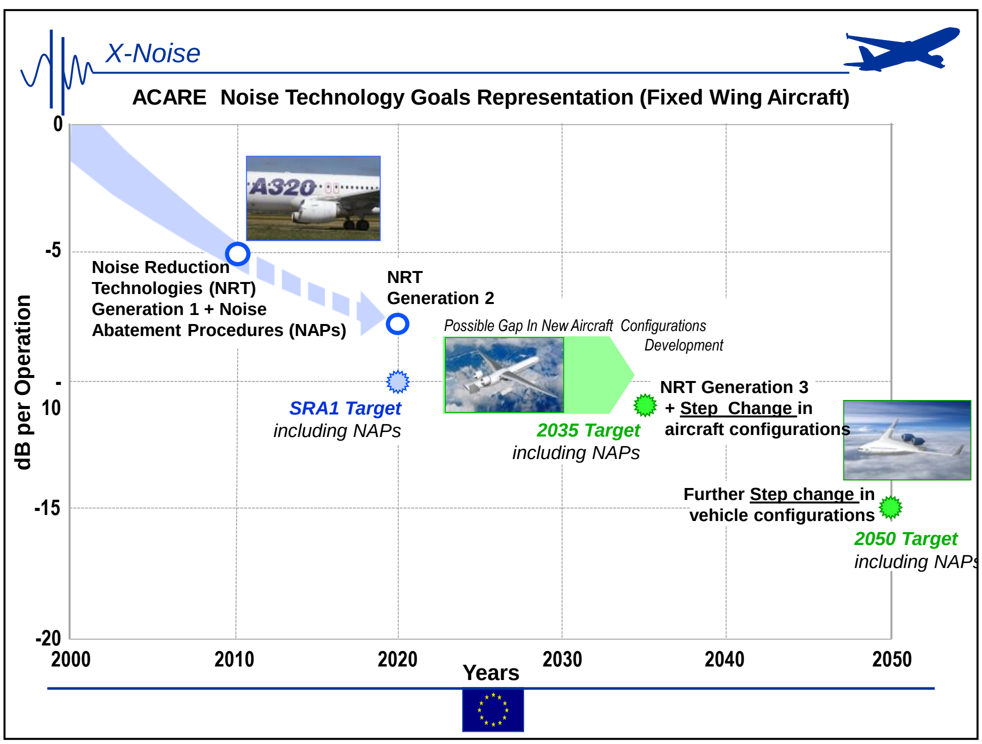


Figure 3.7-7 Another Perspective on Noise Technology Goals

3.8 An Overview of the United States Aircraft Industry

Jeanne C. Yu—*Boeing Commercial Airplane Company*

U.S. aviation companies have invested in reducing airplane noise and increasing efficiency, while maintaining U.S. industry competitiveness. Companies have been introducing substantially quieter and more fuel-efficient airplanes. However, community complaints about noise have been on the rise. Air traffic management approaches are being developed and implemented, along with technological improvements in airplane design and engines, to address ongoing challenges.

Jeanne Yu, Boeing Commercial Airplanes' director for technology integration, presented an overview of the U.S. aircraft industry. She pointed out that the discussion would include an important global context, given the international nature of the industry.

Yu began by emphasizing the huge influence of the global aviation industry: 38 million flights carry 3.57 billion passengers annually, she pointed out, which supports nearly 63 million jobs worldwide and translates into a $2.7 trillion global economic impact in terms of gross domestic product (GDP). Boeing alone predicts a need in the next couple of decades for as many as 39,000 new airplanes—value of these new planes: nearly $6 trillion. Many new deliveries will be in North America, as well as other regions such as Asia, Europe, and the Middle East.

Considerations in introducing new, more fuel-efficient, quieter airplanes include fuel price, environmental factors, and airplane capabilities, among other factors, as depicted in Figure 3.8-1. To maintain U.S. market share, manufacturers focus heavily on production costs and faster production rates. Despite challenges, companies have been introducing significantly quieter, more fuel-efficient commercial jets. Figure 3.8-2 shows the aviation's "strong track record" of reducing the noise footprint while also improving fuel efficiency and reducing CO_2 emissions.

Community noise around airports has been reduced by technological advancements such as the use of lighter composites, high-bypass-ratio engines, modern high-lift devices, noise-reducing chevrons, lower tip speed fans, high-temperature technology, and advanced acoustic linings. Noise signature research and tools play a crucial role in supporting quieter (and more fuel-efficient) designs, Yu stated. Flight test data over noise measurement arrays, correlated with acoustic camera technology, provide the ability to pinpoint—and manage—sources of noise.

While airplanes are getting quieter, as reflected in Figure 3.8-3, the number of operations—and airport neighbors' complaints—are on the rise. In addition, air traffic management (ATM) advances are being implemented, as presented in Figure 3.8-4, that allow airplanes to fly more quietly. Today's ATM capabilities include required navigation performance (RNP) capability, as pilots, air traffic control, and navigation providers are becoming comfortable with new technologies. RNP and GPS-based global navigation satellite landing systems (GLS) capability have been shown to have direct noise benefits.

Trials with airport stakeholders, Yu said, have accelerated the adoption of new procedures for more precise route planning that fully capitalize on airplane navigation capabilities. A *Managing the Impacts of Aviation Noise* guide for industry was released by Civil Air Navigation Services Organisation (CANSO), and Airport Council International (ACI) shares best practices and recommendations to help airports in engaging stakeholders in local transformations.

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Innovation ensures U.S. competitiveness, Yu stated, and innovation-associated challenges are not addressed by airplane technology for noise and emissions alone. Some additional challenges are listed in Figure 3.8-5. Yu stated that to address these hurdles, collaboration is required among representatives of the airline industry, government, and academia.

Yu spoke next about Boeing's ecoDemonstrator Program, which has accelerated innovation through a culture of "learning by doing." Every 18 to 24 months, an airplane is selected as a platform for testing new technologies, a step toward developing solutions faster. Noise-related technologies matured by the program include the ecoDemonstrator 737-demonstrated variable-area fan nozzle, adaptive trailing edge, and low-noise approaches. Additional technologies were developed under the ecoDemonstrator 787, 757, and the Embraer E170, as shown in Figures 3.8-6, 3.8-7, and 3.8-8, respectively.

Yu concluded her presentation with some important points about "creating a better future together."

- Every new airplane is quieter than the one before because of technological investments in the prior decade
- Airplane and operational advances help lower noise to communities
- Advances continue in the areas of airplane design, engines, and air traffic control
- Working together to engineer a future where air travel can continue to grow and be quieter and more efficient
- Addressing manufacturing challenges of cost and production rate to retain U.S. competitiveness in aviation and enable technology advances

It was the last 20 years' investment that made the progress to date in aviation possible, and "we've got to start the investment for the next 20 years now," Yu said. "So, I think it's our responsibility, and I look forward to working with all of you to create a better future together."

Figure 3.8-1 *Wide Range of Market Considerations*

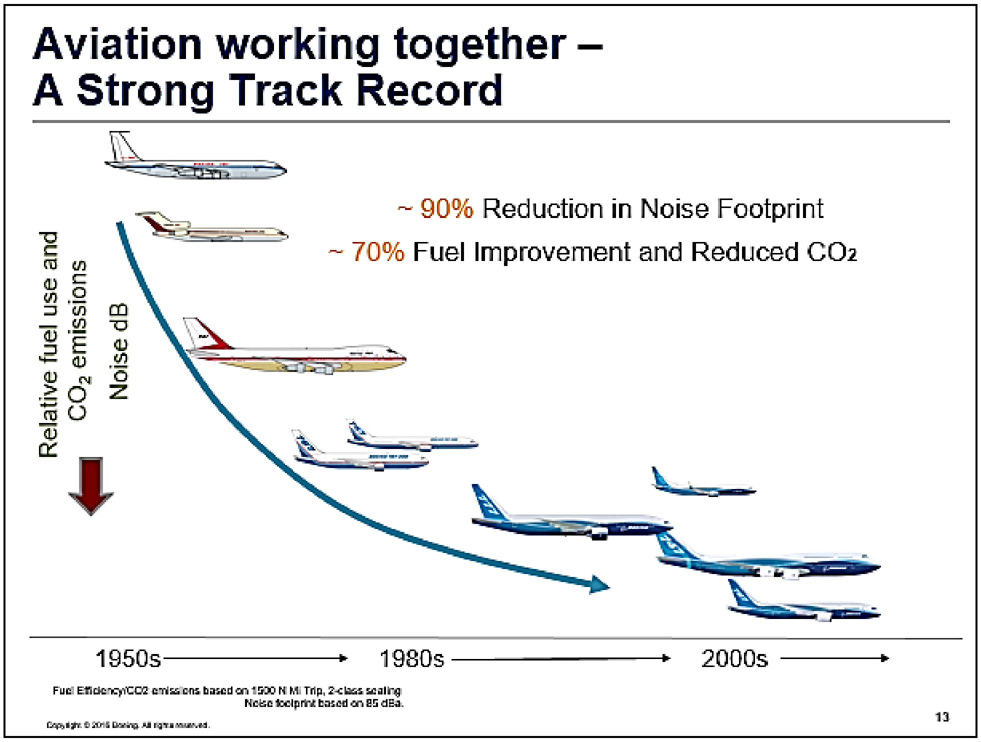

Figure 3.8-2 *Record of Noise Reduction, Fuel Improvement*

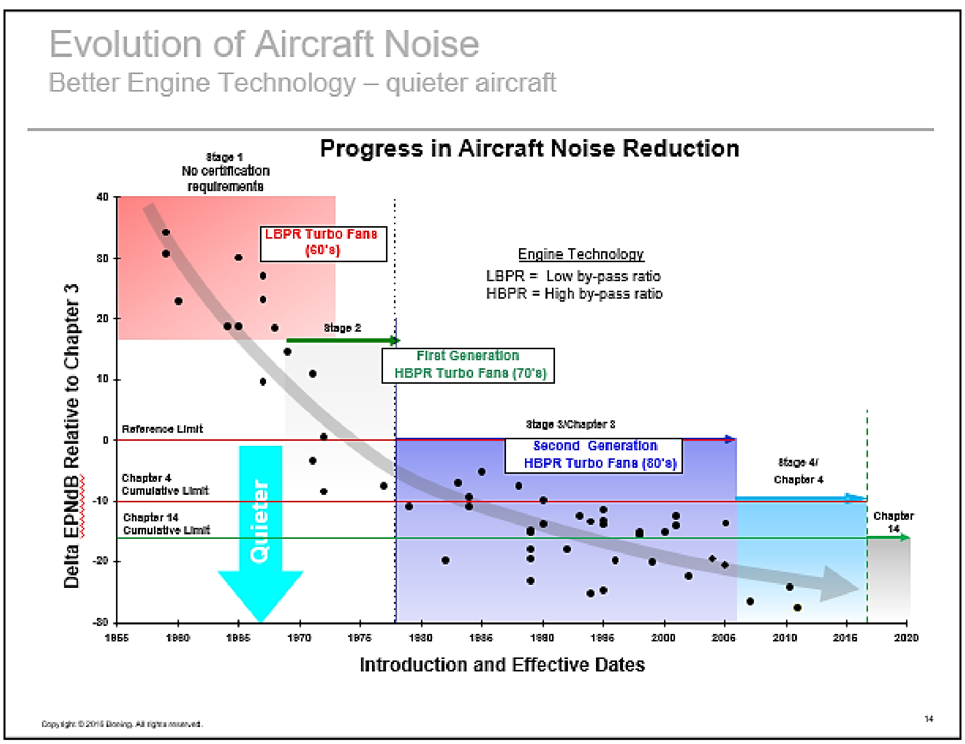

Figure 3.8-3 *History of Aircraft Noise Reduction*

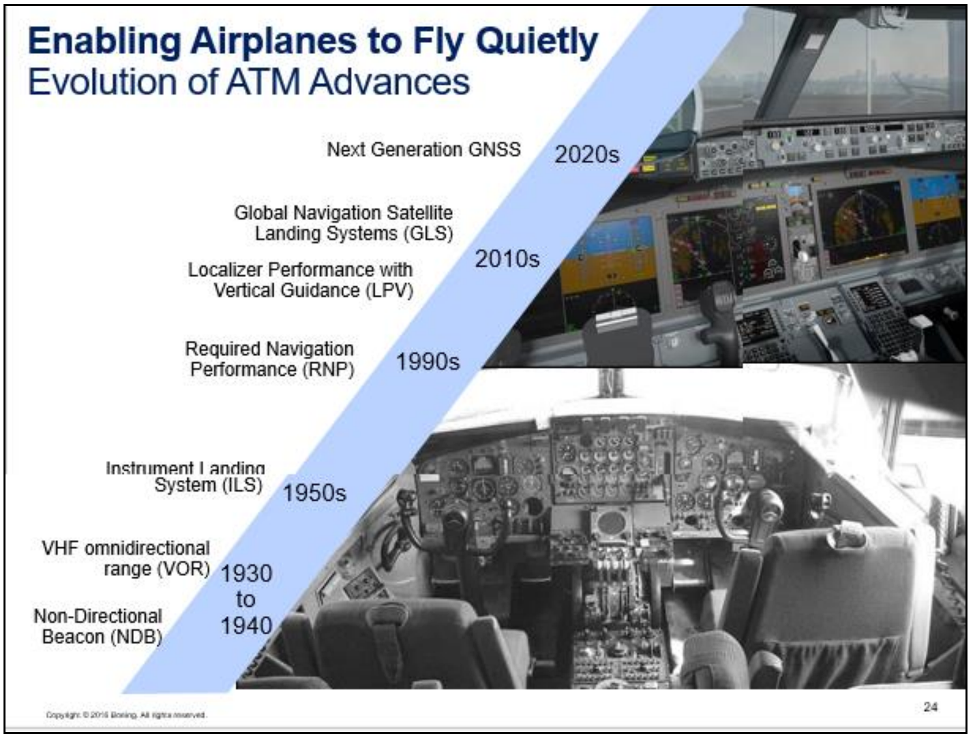

Figure 3.8-4 *Air Traffic Management (ATM) Advances for Quiet Flight*

Figure 3.8-5 *Some Challenges to Innovation*

Figure 3.8-6   *Advances Have Emerged from ecoDemonstrator 787*

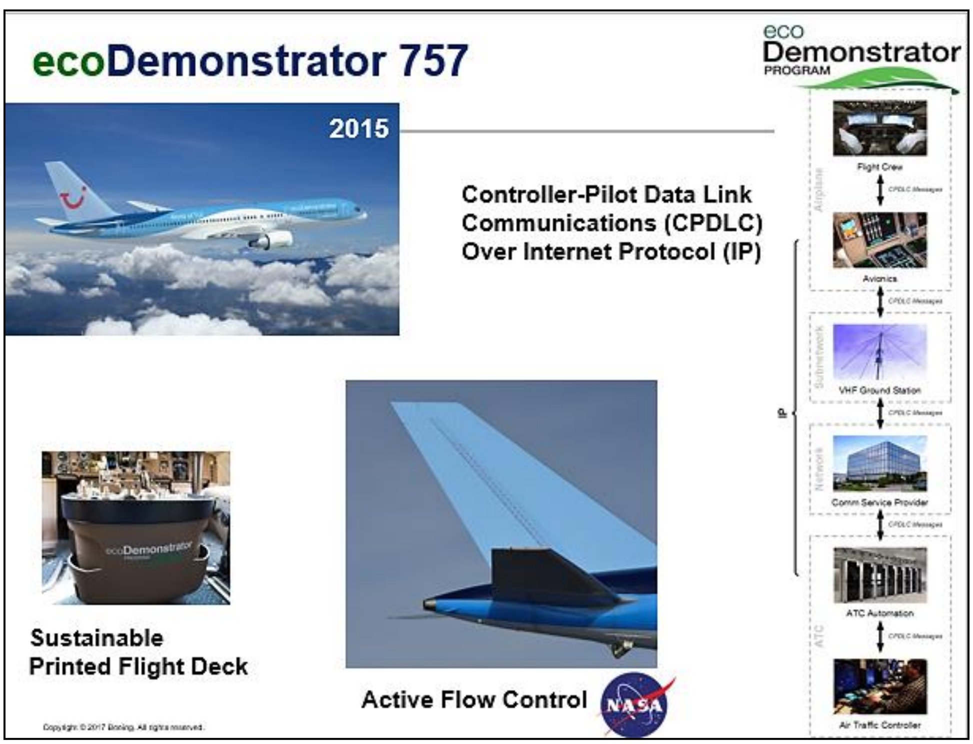

Figure 3.8-7   *Advances Have Emerged from ecoDemonstrator 757*

Figure 3.8-8 *Advances Have Emerged from ecoDemonstrator Embraer*

3.9 Panel Discussion—Day 2: Achieving a Low-Noise Future

Panel Moderator: Stephen Alterman, *Cargo Airline Association*

This panel, which took place toward the end of the workshop's second day, allowed panelists and all participants to discuss issues on which they wanted further clarity. Discussion touched on a wide range of aviation topics, including the status and promise of active noise control; unducted fans and the question of their usefulness in actual flight; the promise of the open rotor; the possibility of certification noise standards for supersonic aircraft over land; and local authorities' application of land-use controls. The primary dialogue focused, however, on whether aeronautics investment by the U.S. Government is adequate for the need. The consensus: No, public investment in aeronautics falls far short and threatens this country's global leadership position in aviation, especially given the immense government support in other countries—notably, The European Union and China.

This Day 2 panel discussion, moderated by the Cargo Airline Association's President Stephen Alterman, offered an additional opportunity for questions for the day's presenters, as well as the chance for panelists and attendees to elaborate on workshop issues of particular interest.

An attendee raised the question of feasibility, from both technical and economic standpoints, of introducing active noise control—on the ground and in the air. Industry opinions differ, the questioner pointed out, with some thinking this type of noise control may not be possible.

First, the question was addressed by a panelist from the physics perspective. Vibroacoustics and aeroacoustics present challenges, he said, elaborating that complicated issues arise related to the way sounds are transmitted to the air, and the use of a transducer and the causality issues related to achieving a benefit locally and quickly without introducing more drag to the aircraft. Great advances have been achieved in helicopters in terms of active noise canceling for the cabin, however, the panelist pointed out.

A panelist added, from the engine manufacturer's perspective, that the largest impact is fan noise from the engine, and active noise control has not demonstrated reductions in engine fan noise. Given the choice to address the noise at the source in a certifiable, safe way, this would be the preference, another panelist contributed. With technologies being developed today, moving in the direction of higher bypass ratios and architectures for slower fans, noise is being addressed at the source. Standing underneath an Airbus A320 flying overhead on approach recently, the participant shared, the only noise he heard was the airframe noise, not engine noise, showing the successful control of noise at the source that reduced the need for active noise control.

Next, a panelist raised another issue related to airframe and engine development not previously addressed in the workshop: sonic fatigue, i.e., fatigue of aircraft structures caused by high sound levels. While delta wing-type designs with the engines on top can help with this, cabin noise issues are raised by this configuration. Cabin noise and other issues are being addressed through modeling work with NASA, one panelist contributed, emphasizing "that story's yet to be told." While the NASA aeronautics portfolio does not significantly focus on cabin noise reduction, given other current priorities, a NASA representative stated, some progress was made in the area of cabin noise in terms of materials and structural solutions, which had broader applicability.

Next the question was raised whether unducted fans, which some have found promising based on computational modeling and other investigation including flight tests in the 1980s, can achieve fuel burn benefits as well as noise reductions in actual flight. Further study is needed, came the response, given that integrating these unducted fans may be found to provide an insufficient benefit to justify disrupting an entire production system. The change comes with penalties in terms of weight, and cabin noise may go up while no significant community noise improvement is gained.

Options must be kept on the table, a panelist stressed—be those related to the open rotor or other technology—toward achieving the sought-after changes in acoustics, emissions, and energy.

Staying on the topic of the open rotor, a panelist discussed NASA's Environmentally Responsible Aviation Project. In comprehensive ground testing of novel open rotor concepts, the acoustic benefits were even more promising than anticipated.

Speed is an additional point that calls for attention, a panelist said. Turboprops are very efficient, but fly slowly, and gas turbines are efficient and fly very fast, and some published studies suggest the open rotor may optimize at a different speed than current engine speeds.

Another panel member asked whether it is realistic to expect certification standards in the foreseeable future for supersonic aircraft over land. Yes, some panelists responded. The international community has been engaging through ICAO, and NASA has been working closely with the FAA, to understand the necessary steps for changing these rules that would of course affect the X-Plane. A panelist added that industry efforts are meanwhile ongoing to advance a conventional configuration to effect a full boom over water and not worry about flying supersonic over land. Another option would be aircraft flying at a low supersonic speed and taking advantage of atmospheric properties so the boom would not reach the ground. The results of comprehensive wind tunnel testing and computation work shows that the design of this aircraft is feasible. The significant importance of X-plane or X-system development was emphasized.

Opining that the consideration of new standards is guided by current technology's ability to meet the would-be requirements, a panel member asked for other's thoughts on this subject. An FAA representative affirmed that the standard-setting process, historically and currently, looks at available technologies in evaluating the stringency levels to be considered.

It was asked whether enough is being done on projects that could be beneficial with respect to noise in the shorter term. Likewise recognizing the need for short-term progress even while longer-term projects continue, a panel member with the FAA mentioned the agency's collaboration with MIT and MassPort to focus on these types of operational strategies. Landing at steeper approach angles could make sense, but then all aircraft must be properly equipped. There may be promise in modifying aircraft speeds coming in. But the most important thing currently, he emphasized, is improving community outreach to help them understand the FAA's and airport's perspective. Even where changes may seem relatively simple at first blush, a panelist pointed out, in-depth analysis can be required—for safety certification, for example—and a burden can be placed on the aircraft industry to make any modifications.

On the different subject of land-use controls, a discussion took place on how to get local governments to use their land-use authority to the benefit of the air system. The federal government is limited in its authority in this area, so the question is how to provide the tools and guidance so local governments might exercise their land-use authority to the aviation system's benefit. The FAA welcomes ideas on how to deal with such land-use restrictions.

The moderator put the question to the panel of how to identify outreach needs and optimally include appropriate stakeholders in the process. A participant suggested that airplane part manufacturing facilities, if distributed around the country, could improve local economies. Another idea, he said, is to define RNAV paths more in keeping with existing noise-exposed roadways and broaden highway right-of-ways, i.e., helping to mask aircraft noise.

A panelist recognized the importance of cost sharing, but said that some technological improvements that aircraft manufacturers are working on with the FAA and NASA under the CLEEN program (Continuous Lower Energy, Emissions and Noise) could achieve improvements in the shorter term. For example, the parties are collaboratively working on integrating the engine with current technology with aircraft's flight management systems with the air traffic management system. This work would help address safety concerns, allowing more aggressive climb and descent paths that could minimize noise impacts on communities.

The panel also addressed the question of the Department of Defense's role in quieting commercial aircraft. A close link has always existed between advancements in the military context and benefits on the civilian side, a participant noted reduced fuel burn as an example, while emphasizing that noise is not a driving factor from the military perspective. On the other hand, the Air Mobility Command serves as an example where reduced noise is a concern.

Turning to the issue of public/private partnerships—the success of which was a common theme in the day's sessions—the panel was asked whether U.S. Government investment in partnerships to advance aircraft technology is sufficient. The answer was put in the perspective of Chinese aviation investment, which by some estimates will be $300 billion over 20 years. Although the exact number may be debated, U.S. investment is a small fraction, even considering funds from the Department of Defense, NASA, the FAA, and all the U.S. engine companies.

Aerospace is the largest U.S. export, a participant reiterated, exceeding all other exports combined in most years. Sustaining the country's position as international aerospace leader, while sustaining high-quality jobs in the industry requires a larger investment, he said, in what he characterized as an "aeronautics moonshot." More funding is required to support revolutionary projects like the X-Plane, which "envisions the art of the possible," a panelist added. And another added, from the aircraft manufacturer's vantage point, that current funding may support incremental improvements, but it proves difficult to "leap frog" the industry without additional support. She added that more money is needed to continue to grow the necessary talent in the United States to maintain a strong aerospace industry, and that just a small reallocation of NASA's space budget could nearly double the aeronautics investment. The moderator concurred that, from the airline perspective government investment also falls short.

Workshop participants were interested in a quantification of investment needs, but did not have a specific number to offer. They did reference public information relevant to the consideration, however: NASA's 10-year New Aviation Horizons initiative laid out in the 2016 president's budget would devote more than a billion dollars to the X-Plane program over the decade time frame. Pursuing a wide range of aircraft concepts would add to the required investment, and could be accomplished through public/private collaboration. With a partnership between government and private entities, a workshop participant opined, an amount of about $2 billion over five years could represent a "good down payment" to pursue promising ideas. He added, for context, that a recent GAO report put U.S. industry spending for aerospace R&D at $14 billion in 2015 alone.

One panelist, asked earlier in the workshop what keeps him up at night, made the following statement:

"*I talked about risk and our inability to take it. Here's a flip side to that and that's other people will take that risk. We just talked about China and the position that they're coming from. We clearly have a leadership position in aviation within the world today when we're talking about the United States. They [China] do not. They want to achieve that. So they're willing to take the risk to learn along the way to get to that point. And so it's not just the dollars, but it's the mentality that comes along with it. And so I think one of the takeaways from this workshop is we've demonstrated that we as a community have a tremendous ability to make progress, and we talk about the 95 percent reduction in the noise exposure. Imagine what noise complaints would be like today if we didn't have that type of success*."

3.10 Closing Remarks: Appreciation for a Successful Workshop

On behalf of the commercial aviation workshop steering committee, committee members Adnan Akay, Gregg Fleming, Robert Hellweg, George Maling, and Eric Wood made concluding remarks. Primarily, grateful appreciation was extended to all who contributed generously of their time and expertise to make the workshop a success. Special thanks were offered to NASA's Jay Dryer, and the FAA's James Hileman and Rebecca Cointin for their organizational helping hand, and to the additional experts who attended and presented from their wide-ranging perspectives on behalf of government, industry, and academia.

Grateful acknowledgment was extended as well to the National Academy of Engineering for hosting and enthusiastically supporting the forum, which was a unique early instance of a member-initiated workshop under an NAE policy announced in October 2016. Among those thanked for their invaluable help were the Academy's President C.D. Mote, Jr., Executive Officer Alton Romig, Program Office Director Proctor Reid, and Senior Program Assistant Michael Holzer.

Steering committee members expressed optimism that the workshop and resulting report would contribute to the ultimate goal of maintaining U.S. leadership in commercial aviation. Attendees were reminded that the National Academies of Sciences, Engineering, and Medicine is an independent organization providing unbiased advice to the government, and that the use of workshop information and reports before Congress or others is not to be seen as representing the views of the National Academies.

Next steps were also summarized: Consideration was being given to a workshop in 2018 about noise from unmanned aerial systems (UAS). Those interested in contributing their expert viewpoint on this exciting, if controversial, emerging topic were invited to contact the committee.

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 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

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Bilkent University

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President
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The Boeing Company

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Aurora Flight Sciences Corp.
and MIT

Appendix C.

Acronyms and Definitions

ACARE	Advisory Council for Aeronautics Research in Europe
ACI	Airports Council International
ACRP	Airport Cooperative Research Program
AEDT	Aviation Environmental Design Tool
AFRL	Air Force Research Laboratory
ANOPP	Aircraft Noise Prediction Program (NASA)
ARMD	NASA Aeronautics Research Mission Directorate
ASCENT	Aviation Sustainability Center (FAA)
ATC	Air Traffic Control
ATM	Air Traffic Management
BADA	Base of Aircraft Data – an aircraft performance model
BEA	Bureau of Economic Analysis
BLI	Boundary layer ingestion
BLS	Bureau of Labor Statistics
BOS	Boston Logan International Airport
BPR	Bypass Ratio
BTS	Bureau of Transportation Statistics
BWB	Blended wing body
CAA	Cargo Airline Association
CAAFI	Commercial aviation alternative fuel initiative
CAEP	ICAO Committee on Aviation Environmental Protection
CANSO	Civil Air Navigation Services Organization
CFR	US Code of Federal Regulations
CIP	Capital Improvement Plan
CLEEN	Continuous Lower Energy, Emissions and Noise (FAA program)
CO_2	Carbon Dioxide
CROR	Counter rotating open rotor engines
Cumulative Noise level	Arithmetic sum of EPNL values in dB measured at three FAA aircraft noise certification points
CVC	Constant Volume Combustion
DARPA	Defense Advanced Research Projects Agency
dB	Decibel, a logarithmic unit of measurement in acoustics and electronics
dB(A)	A-weighted sound level accounting for human perception of sounds at low-, mid-, and high frequencies
DDA	Delayed Deceleration Approach
DFW	Dallas/Fort Worth Airport
DoD	US Department of Defense
DNL	Day Night Level (a sound level metric that has a 10 dB penalty for night noise)

DOT	US Department of Transportation
EPNL	Effective Perceived Noise Level in dB (used in FAA certification of aircraft)
EPNdB	Effective Perceive Noise weighted sound level
EU	European Union
FAA	Federal Aviation Administration
FEIS	Final Environmental Impact Statement
FHV	Fuel heating value
FLOPS	NASA's Flight Optimization System
FMS	Flight management system (FAA)
FPR	Fan Pressure Ratio
FY	Fiscal Year
GAO	US Government Accountability Office
GDP	Gross Domestic Product
GTF	Geared turbofan
GLS	GPS-based global navigation satellite landing system
GNSS	Global Navigation Satellite System
HA	Highly annoyed
HBPR	High Bypass Ratio
HOV	High occupancy vehicle
HWB	Hybrid Wing Body
Hz	The unit of frequency
ICAO	International Civil Aviation Organization
IFR	Instrument flight rules
I-INCE	International Institute of Noise Control Engineering www.i-ince.org
INCE-USA	Institute of Noise Control Engineering of the USA www.inceusa.org
DDA	Delayed Deceleration Approach
KLEMS	Capital, labor, energy, materials, and services
LAX	Los Angeles International Airport
LBFD	Low Boom Flight Demonstration
LBPR	Low Bypass ratio
L/D	Lift/Draft
Lden	Day night evening sound level in dB (used in European regulations)
Ldn	Day night sound level (see DNL) in dB
LGA	New York LaGuardia Airport
Lmax	Maximum noise level in dB
LTO	Landing Take-off
MassPort	Massachusetts Port Authority
MEMS	Microelectro-mechanical systems
MFH	Million flight hours
MFP	Multifactor Productivity
MIT	Massachusetts Institute of Technology
MMC	Metal matrix composite
MOU	Memo of understanding
NACA	National Advisory Committee for Aeronautics
NAE	National Academy of Engineering

NASA	National Aeronautics and Space Administration
NCEJ	Noise Control Engineering Journal
NCF	Noise Control Foundation
NEPA	National Environmental Protection Act
NextGen	Next Generation Air Transportation System (FAA)
NNI	Noise/News International
NOx	Nitrogen oxide
NPIAS	National Plan of Integrated Airport Systems (FAA)
OBJ	NASA N+2 Objective
OPR	Overall pressure ratio
ORD	Chicago O'Hare International Airport
P3	Public-private partnerships
Pax	Passengers
PBN	Performance based navigation
PDR	Preliminary Design Review
PHX	Phoenix Sky Harbor International Airport
PID	Parameter identification
PR	Pressure ratio
R&D	Research and development
RJ	Regional jet aircraft
RNAV	En Route Area Navigation
RNP	Required navigation performance
RTCA	Radio Technical Commission for Aeronautics
RTSM	Real-time stability margin
SEL	Sound Exposure Level in dB
SFC	Specific fuel consumption
SID	Standard Instrument Departure
SLST	Sea level static thrust
STARC-ABL	Single-aisle turboelectric aircraft with aft boundary layer propulsion
STEM	Science, Technology, Engineering, and Math
TASOPT	Transport Aircraft System Optimization program
TBO	Trajectory Based Operations
TEC	Thermionic Combustion
Thr	NASA N+2Threshold
TQA	Technology for a Quieter America
TRL	Technology Readiness Level
UAS	Unmanned aerial systems or unmanned aircraft systems
VFR	Visual flight rules
WHO	World Health Organization
YOY	Year over year

Appendix D

NASA Auralizations of Current and Future Aircraft Overflights

Presenter Richard Wahls—*NASA*

Auralizations together with video of current and future aircraft have been prepared in the NASA project office of Environmentally Responsible Aviation. This is a fascinating tool that lets you hear simulated sounds of various current and future aircraft.

Embedded in the left side of the figure below is a NASA auralization and video of a State-of-the-Art aircraft on approach. For comparison, the right-side frame of that figure presented by Wahls includes an auralization and video of a Hybrid Wing Body aircraft on approach. These auralizations and videos (MP4 files) should be active in the digital pdf copy of this report. Left click the play buttons below to play the two NASA files. The audio is not calibrated to a specific level, but relative differences between aircraft are valid to compare. Consider increasing the volume of your speakers.

Alternatively, the above two NASA files can be opened at:
https://stabserv.larc.nasa.gov/flyover/AIAA-2013-0542/soa_approach_centermic.mp4
https://stabserv.larc.nasa.gov/flyover/AIAA-2013-0542/hwb_approach_centermic.mp4

Auralizations have also been made by NASA for small propeller-driven aircraft and for the supersonic low-boom aircraft. Additional NASA sound files and movies are available for download at: http://stabserv.larc.nasa.gov/flyover/

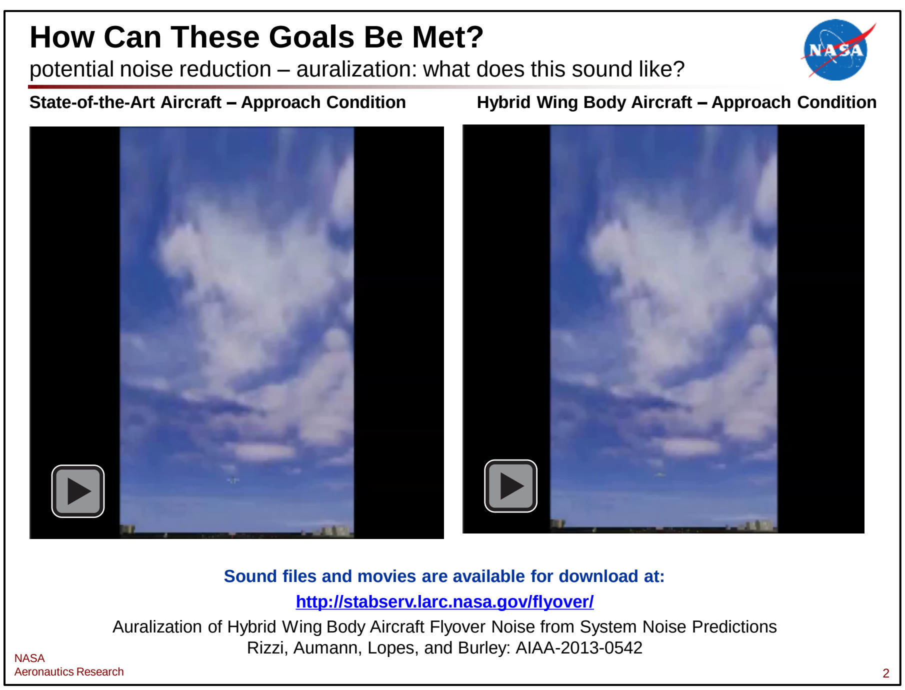

Figure D-1 *NASA Auralizations of Aircraft Overflights*

Maintaining America's Global Leadership in Aviation Technologies





Boeing, Lockheed Martin, Pratt & Whitney, General Electric