Engineering a Quieter America

Noise Around Airports: A Global Perspective

A Technology for a Quieter America (TQA) Virtual Workshop
November 1-4, 2022

A workshop organized by

The INCE Foundation

hosted by

International Institute of Noise Control Engineering and

The National Academy of Engineering, Washington, DC

Tamar Nordenberg, rapporteur

edited by

Adnan Akay, Patricia Davies, Eric H. Ducharme, Gregg G. Fleming,
Robert D. Hellweg, and Eric W. Wood

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VieCommunications@gmail.com

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GREGG G. FLEMING
U.S. DOT Volpe National Transportation Systems Center
Director of Policy, Planning, and Environment

ROBERT D. HELLWEG, JR.
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Past President, Institute of Noise Control Engineering of the USA

ERIC W. WOOD
Acentech Incorporated
Former Director, Noise and Vibration Group,
President, INCE Foundation
Past President, Institute of Noise Control Engineering of the USA

[1] Deceased, June 9, 2022

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[2] Deceased, June 9, 2022

PREFACE

This document is the final report on a virtual workshop hosted by the International Institute of Noise Control Engineering (I-INCE) and the US National Academy of Engineering (NAE) on November 1-4, 2022. This workshop, "Noise Around Airports: A Global Perspective", was organized by the INCE Foundation under a 2016 NAE policy on member-organized events. The steering committee consisted of Adnan Akay, visiting professor Sapienza University of Rome; Patricia Davies of Purdue University; Eric Ducharme, member NAE; Gregg G. Fleming with the Volpe National Transportation Systems Center; Robert D. Hellweg, Jr. with Hellweg Acoustics; George C. Maling, Jr., member NAE; and Eric W. Wood, with Acentech.

This "Noise Around Airports: A Global Perspective" workshop report includes a summary of each presentation and images of selected slides shown at the meeting. Presentation summaries are followed by appendices—Appendix A with the workshop program, Appendix B with a list of attendees, and Appendix C with a list of acronyms.

NAE executive officer and chief operating officer Alton Romig welcomed participants on the workshop's first day. Welcoming remarks on days 2, 3, and 4 were provided by NAE member Eric Ducharme, I-INCE president Robert Bernhard, and NAE senior scholar and senior director of programs Guru Madhavan, respectively. The workshop's four keynote addresses focused on global perspectives through 2050, the noise situation at west coast US airports, aircraft noise in Japan, and a UK perspective on noise metrics for airspace redesign

ACKNOWLEDGMENTS

Support from the National Academy of Engineering and the International Institute of Noise Control Engineering in hosting the workshop is very much appreciated. Special thanks are extended to NAE meetings coordinator Sherri Hunter and senior audio visual technician Ahmir Robinson.

Vital assistance was also provided by rapporteur Tamar Nordenberg. She wrote the summaries of the workshop presentations, which were then reviewed by the presenters. With technical assistance from the editors, she produced a cohesive, readable report.

Report editors Adnan Akay, Patricia Davies, Eric Ducharme, Robert Hellweg, Gregg Fleming, and Eric Wood put in many hours in the preparation of this report, and are grateful to the paper authors for their presentations at the workshop and for reviewing the summaries of their presentations.

The support of the INCE Foundation is gratefully acknowledged. Finally, thanks to the NAE's Committee on Technology for a Quieter America (TQA), chaired by George Maling, which produced the foundational 2010 NAE *Technology for a Quieter America* report with its numerous important findings and recommendations.

DEDICATION

This report is dedicated to

Dr. George C. Maling, Jr.

For his tireless dedication, contributions, and leadership he provided for Technology for a Quieter America activities.
George passed away during the last stages of preparing this report.

CONTENTS

1. Executive Summary

The "Noise Around Airports; A Global Perspective" workshop, held in November 2022, examined the state of airport noise globally; and progress made in various countries toward reducing airport noise and its negative effects on the public. The workshop included welcome remarks each day, tributes to the Technology for a Quieter America program founders, and twenty-three presentations under four main themes: community response, noise situations around airports, the impact of noise around airports, and relevant technology considerations.

WELCOME REMARKS

On the first day of the meeting, which focused on community response to airport noise, Adnan Akay welcomed participants from around the world. He summarized the history of the National Academy of Engineering (NAE) Technology for a Quieter America workshops and introduced the organizers and steering committee members.

Alton Romig, executive officer of the NAE, added his welcoming remarks on behalf of the Academy. Romig, who had a long career in aerospace and defense, mentioned advances in aerospace technologies utilizing independent control of fan and turbine speeds to optimize fuel efficiency and reduce noise, as well as open rotor and third-stream engines.

Eric Ducharme, NAE and formerly GE Aviation, welcomed workshop participants on the second day, which focused on noise situations around airports. Ducharme noted the significant improvement in aircraft noise over the years. He also said that airport noise abatement requires consideration of not only source noise and the use of abatement technologies, but also of airport land-use management, noise abatement procedures during flight, and curfews and other operating restrictions.

Robert Bernhard, the outgoing International Institute of Noise Control Engineering (I-INCE) president, welcomed workshop participants on the third day, which focused on the impact of noise around airports. Bernhard praised the late George Maling for his trailblazing contributions in the area of noise control engineering.

Guru Madhavan, senior director of NAE programs, welcomed workshop participants on the meeting's final day, which focused on relevant technology considerations. Madhavan described the NAE's Forum on Complex Unifiable Systems (FOCUS) program, which explores the complexities relating to health, security, democracy, urbanization, infrastructure, the economy, and the environment.

TRIBUTES TO THE FOUNDERS OF THE TECHNOLOGY FOR A QUIETER AMERICA PROGRAM

Eric Wood led the workshop tribute to George Maling, who is well known as a giant in the field of noise control engineering. In 2006 Maling was appointed as chair of an NAE project that resulted in the publication of the 2010 NAE consensus report *Technology for a Quieter America*. He led the steering committee for the first ten TQA workshops and reports. Maling passed away on June 9, 2022.

Robert Hellweg led the workshop tribute to William Lang—describing his "long and distinguished career in noise control engineering and acoustics" and spotlighting, in particular, Lang's contributions to the NAE *Technology for a Quieter America* consensus report and the series of workshops following from the report. Lang passed away shortly after the 2016 TQA workshop on technology transfer in the noise control arena.

WORKSHOP PRESENTATIONS IN FOUR PRIMARY AREAS

Community Response

The first keynote speaker was Gregg Fleming, of the U.S. Department of Transportation's Volpe National Transportation Systems Center who has long participated in international activities related to aviation noise. His address focused on global perspectives of aviation noise through the year 2050. Fleming noted that the International Civil Aviation Organization's Committee on Aviation Environmental Protection (ICAO/CAEP) conducts a global environmental trends assessment every three years, examining international trends in aviation noise as well as emissions and fuel burn. He noted that ICAO/CAEP's sophisticated modelling, using advanced databases with worldwide scope, points to the promise of noise-neutral growth at least through 2050. He also emphasized the importance of government investment to help improve technology, and research funding from U.S. government agencies such as the National Aeronautics and Space Administration (NASA) and the Federal Aviation Administration (FAA), could bring to support new designs to aviation that help make aggressive, effective noise control scenarios a reality.

Marion Burgess of the University of New South Wales described the different measures in place in Australia to mitigate noise affecting communities around airports. She explained the country's flight path design principles that include noise abatement measures developed by Air Services Australia, which also undertakes extensive community consultation on topics including noise data and flight path data. She emphasized the importance of an independent aircraft noise ombudsman to investigate noise complaints and recommend appropriate corrective measures.

Tânia Caldas from the Federal University of Rio de Janeiro spoke about community noise issues around Brazilian airports including community annoyance, current regulatory noise management approaches, and opportunities to address conflicts between airports and surrounding communities. Caldas indicated that achieving a national airport noise management program requires identification of financial support for mitigation measures, agreement on goals and timelines; and designation of rules for prioritizing inspection and noise control steps.

Stephen Sulprizio of the Massachusetts Port Authority (Massport) shared his expertise on community noise around Boston Logan International Airport from his perspective as manager of the airport's Noise Abatement Office. Sulprizio focused his presentation on the operational context of aircraft-related noise around his airport. Topics included: an overview of the airport's operations and overflight noise; the airport's noise abatement program; its area navigation (RNAV) study conducted with the Massachusetts Institute of Technology (MIT) and the Federal Aviation Administration (FAA); its Residential Sound Insulation Program; and its approach to airport noise complaints.

Amber Goodspeed also with the Massachusetts Port Authority described Massports approaches for minimizing noise disturbance in the community by using systems for ongoing noise monitoring and reporting. Such approaches include a database to analyze sound exposure levels and a "Fly Friendly" Touch and Go program to minimize disturbance over sensitive areas.

Laurent Leylekian of the French Aerospace Lab ONERA spoke about the EU Aviation Noise Impact Management Through Novel Approaches (ANIMA) research project and the broader issue of the challenge of managing aviation noise. The overarching objective of ANIMA was to develop methodologies, approaches, and tools to address the impact of aviation noise, while enhancing the capability to respond to a growing demand for air travel. The main product of ANIMA was a methodology to support airport authorities wanting to implement noise-related improvements, and not a technology-oriented project dealing with issues such as noise reduction at the source. Communication within this process should be undertaken using an accessible everyday language rather than technical jargon or expert language. ANIMA developed "Noise Platform" provides noise management tools and features dynamic noise maps, Twitter semantic analysis, and noise management software. The ANIMA methodology aims to help communities, airports, and authorities that wish to improve their noise situation but don't know where to start in their quest for consensus.

Terry Blue of the Memphis Shelby County Airport Authority explained that very few complaints are received related to the Memphis Airports operations, thanks to informal noise abatement procedures that are in place, as well as the FAA's updated navigation system and certification standards.

Peter Kirsch, a lawyer with Kaplan Kirsch & Rockwell, shared his expertise about airport proprietors' liability in the United States for noise damages. Airport proprietors can be held liable for noise impacts around US airports. But, while case law and federal and state statutes have long allowed for compensation under certain circumstances interfering with the use and enjoyment of a property, requirements to show sufficient harm are strict and these cases rarely succeed.

Noise Situations Around Airports

Vincent Mestre, an acoustical consultant, gave the second keynote address which focused on the noise situation at four West Coast US airports, all of which have noise rules that are among the strictest in the country. Mestre indicated that only a third of annoyance may be due to acoustic factors, while the rest is attributable to are non-noise-related issues such as visual intrusion. He recommended that policy decisions should distinguish local versus federal roles in decision making.

Ralf Wagner, with the Berlin Brandenburg Airport, described the two methods the Berlin Airport uses to reduce noise impact around the airport: a single-event noise fee system and a noise protection program. A single-event noise fee system recently replaced a more generalized fee system that was based on certified noise levels for each aircraft type. The noise protection program covers the costs for improvements to control indoor, as well as outdoor, noise levels at homes near the airport. An engineering company performs a thorough examination to determine the improvements necessary, and a calculation is made of the costs.

Ana García Sainz-Pardo, along with Eva Santos González and Antonio Donoso López, spoke about reducing noise annoyance around Spain's Madrid Airport. As experts on the Aviation Noise Team at the state-owned company SENASA, the three provide technical support related to noise and associated annoyance around all of Spain's airports. To encourage quieter fleets, the Madrid Airport implemented two major measures, among others: increased landing charges for the noisiest aircraft, and noise quotas whereby each airline consumes points based on the noise from its fleet operations over the previous year. Other restrictions have also been implemented, according to an airport's size, the sources of noise, and the placement of the closest homes.

Sandra Lancaster with the Dallas Fort Worth Airport discussed how DFW vigorously monitors, and takes steps to curtail noise around its facility. As a central element of its noise control strategy, the airport actively engages with nearby communities to keep them informed of noise-related challenges and involved in mitigation steps. DFW Airport is mindful that changes in US policy could require updates to its current noise policy to aggressively limit noise exposure around its facility. Potentially influential questions on the horizon include: Is day night level (DNL) the right metric, and is a DNL of 65 dB(A) the right level?; How will supersonic aircraft impact airport operations and noise?; and How will urban air mobility vehicles affect community noise levels?

Impact of Noise Around Airports

In the third keynote address of the workshop, Naoaki Shinohara from Japan's Aviation Environment Research Center and, Makoto Morinaga, with Kanagawa University discussed the past, present, and future challenges associated with aircraft noise in Japan and strategies for increasing community acceptance in this context. Shinohara spoke about historical and current challenges and corrective measures. Measures taken by Japan fall into three main categories: reducing noise at the source, improving airport structure/facility, and taking mitigation measures. These categories and associated control strategies have included the introduction of low-noise aircraft, restrictions on night flights, construction of offshore airports, and remedial compensation for actions such as soundproofing of houses. Morinaga discussed the Japanese community response to aircraft noise and possible ways to increase noise acceptance. Despite seemingly effective efforts to communicate with area residents and integrate noise mitigation measures, social surveys indicate an increase in noise annoyance in the 2000s compared with the 1990s. While direct measures of noise exposure are extremely important, attention should also be paid to non-acoustic factors.

Charlotte Clark with St. George's University of London talked about engagement with communities when airport changes are planned, such as design changes on the ground as in airport expansions and changes in airspace configurations. She emphasized that communities are important stakeholders whose input should be thoughtfully considered with respect to the complex issues involved. and notes that the issues involved are complex, and when balancing community benefits and disbenefits, issues of effectiveness and fairness should remain front of mind, and solutions must be created collaboratively.

Truls Gjestland with SINTEF Digital in Norway, discussed factors affecting the results of noise and annoyance surveys around airports. To understand, apply, and meaningfully compare results from such noise and annoyance surveys, careful attention must be paid to how the surveys have been conducted—via phone versus mail, for example. For useful comparisons, surveys must have been conducted using the same methods, or alternatively, adjustments must be made in analysis. Gjestland used the community tolerance level (CTL) method for adjusting annoyance levels for differences in social survey method, response scale, aircraft traffic volume, and airport operational changes. Applying these adjustments to the 2020 FAA Neighborhood Environmental Survey (NES) noise annoyance curves showed that the FAA results were consistent with previous studies. Gjestland questioned the WHO definition of "acceptable noise exposure level" as 10 percent highly annoyed, stating that the definition was too vague and imprecise for use in regulatory standard-setting, since CTL results from a survey on annoyance from aircraft noise can easily differ by as much as +-10 dB, based on how surveys are conducted.

Adam Scholten of the FAA's Office of Environment and Energy spoke about the results of the FAA's Neighborhood Environmental Survey airport noise survey. The survey showed the usefulness of DNL as a metric for quantifying annoyance in the context of airport noise, while recommending the exploration of other measures that could improve quantification of the experience of communities near airports. The NES and follow-on analysis will help to inform the FAA's future noise policy.

Technology Considerations

Darren Rhodes, of the UK Civil Aviation Authority (CAA), gave the fourth keynote address, from a UK perspective on noise metrics for airspace redesign. The CAA is the UK airspace regulator, with responsibility for approving changes to airspace design. The government provides legal direction and environmental guidance to the CAA regarding airspace design considerations, including those related to noise metrics and thresholds. As set forth in its Air Navigation Guidance, government priorities in the aviation arena include limiting the number of people significantly affected by adverse impacts from aircraft noise. Rhodes described the government's guidance on valuing the impacts of noise, including aircraft noise, on health and quality of life.

Eric Wood of Acentech presented audio files from the Volpe National Transportation Systems Center demonstrating takeoff noise from five aircraft, the B707, B727, MD 81, B777, and B787. The files highlighted the substantial progress made between 1959 and 2011 in reducing noise from jet airliners during.

Philippe Strauss with the French Center on Noise Information (CidB) highlighted select lessons from the Quiet Drones 2022 e-symposium, speaking on behalf of himself and presentation contributors Jean Tourret (president, INCE/Europe) and Dick Bowdler (director, INCE/Europe). The 2022 Quiet Drones symposium shed light on the current state of assessment, measurement, standardization, and societal acceptance in the context of noise from drones and eVTOLs. Strauss noted that societal acceptance of these leading-edge air vehicles can only be gained by addressing the many open questions through thoughtful, transparent public engagement. Noise remains one of the largest limiting factors in terms of public acceptance and adoption of drone technology, and engagement with the public is key in the development and acceptability of advanced aerial mobility. Strauss noted that the crucial need for helpful data on these unconventional aircraft.

Karoline Schweiger and Maria Stolz of the German Aerospace Center (DLR) presented their research on vertiports and public acceptance of urban air mobility, noting that while noise is an influential factor in community acceptance of UAM, it is part of a multimodal optimization problem. They described two of their experiments using virtual reality to advance the understanding of people's responses to vehicles flying nearby. These experiments explored effects of and interactions between context, vehicle types, and visual and acoustic exposures. They found that flight height, number of drones, and the area where flights take place affect people's perceptions, and the researchers recommend that these factors should be considered when planning drone missions and developing flight regulations.

Russell Thomas with the NASA Langley Research Center's Aeroacoustics Branch discussed important role enabling research and innovation by industry, government and academia toward quieter aircraft engines and airframes that contribute to sustainable aviation and reduce noise. The speaker discussed both propulsion aeroacoustics and aircraft system noise. Propulsion system related improvements in duct acoustic liner treatments, improved rotor-stator spacing, chevrons, and other areas were described. Propulsion airframe aeroacoustic integration and modeling capabilities with respect to shielding and scattering will be important for novel configurations such as: transonic truss-braced wings, hybrid wing bodies, electrified and distributed propulsion, and open rotors. While challenging, the technology pathways are promising for a future of sustainable aviation with reduced noise aircraft.

Ben Murphy of Boom Supersonic addressed the many tools, methods, and technologies being used to help develop the Overture new supersonic aircraft which is expected to meet the Chapter 14 ICAO noise standard. Many of the innovations developed to achieve this noise reduction are expected to be applicable to subsonic aviation, as well.

Joseph Navarrete, a senior program officer with the Airport Cooperative Research Program (ACRP) within the National Academies of Sciences, Engineering, and Medicine's Transportation Research Board, described the ACRP program's mission, the types of research it undertakes, and ways to contribute to its research projects. Examples of successful ACRP studies include research that led to guidance for airports looking to optimize their storm water management, and research into which products and methods work best for sound insulation of homes.

Closing Remarks

Eric Ducharme closed the workshop with praise for its global perspective and the speakers' specialized expertise covering a broad spectrum of viewpoints. Other attendees commented on the excellent presentations and robust exchange of ideas throughout the workshop.

2. Introduction

Background

The 2010 National Academy of Engineering report *Technology for a Quieter America*[1] (TQA) emphasizes the importance of engineering to the quality of life in the United States, and in particular the role of noise control technology in achieving a quieter environment. Subjects addressed include environmental noise in communities; control of hazardous noise in workplaces; metrics for assessing noise and noise exposure; noise control technologies; standards and regulations for product noise emissions; cost-benefit analysis for noise controls; and the role of government, education, and public information in noise control. The report offers a wide range of related recommendations, implementation of which promises to reduce Americans' noise exposure and improve the ability of U.S. industry to compete in world markets where increasing attention is being paid to products' noise emissions.

The Workshop

This report is a summary of the Noise Around Airports; A Global Perspective workshop held as a virtual event on Nov. 1–4, 2022. The workshop is the 12th in a series of TQA follow-on workshops organized under a policy announced by the NAE in 2016 that allows for member-initiated events. This workshop series began in 2012 with a meeting on reduction of motorcycle noise. A number of workshops followed, on topics such as quieter pavements, employee noise exposure in manufacturing, noise from commercial aviation and air mobility vehicles, technology transfer, and noise control engineering education.

This "Noise Around Airports; A Global Perspective" workshop was hosted by the NAE and I-INCE, and organized by the INCE Foundation. This report, like others for the workshop series, was prepared by a professional science writer from presentation transcripts. All presenters had an opportunity to review the summaries before publication.

The subject of this workshop has a long history and much progress has been made over the years. All told, 30 presentations were made during the workshop, all of which are summarized in this report. Meeting participants were welcomed with opening remarks each day by Adnan Akay, professor at Sapienza University of Rome; Alton D. Romig, Jr., NAE executive officer; Eric Ducharme, NAE member; Robert Bernhard, I-INCE president; and Guru Madhavan, NAE member. Presentations by experts were provided for airports in Australia, Brazil, France, Norway, the United Kingdom, Germany, Japan, Spain, and the United States. Tributes for our colleagues George Maling and William Lang are also included in this report.

[1] https://www.nae.edu/27531/Technology-for-a-Quieter-America

3. Welcoming Remarks

3.1 Workshop Introductory Remarks

Adnan Akay—Sapienza University of Rome

Adnan Akay, visiting professor at the Sapienza University of Rome and professor emeritus with Carnegie Mellon University and Bilkent University in Ankara, Turkey, opened the "Noise Around Airports: A Global Perspective" workshop by providing a brief history leading up to this workshop, introducing the workshop organizing committee, and acknowledging individuals and organizations that made invaluable contributions to the workshop.

The 2010 NAE *Technology for a Quieter America* (TQA) report (available at (https://www.nae.edu/35649/Technology-for-a-Quieter-America) conveyed the importance of engineering to quality of life and the role of noise control technology in achieving a quieter environment. Thirteen workshops have been held to date to expand on topics outlined in the report. The workshops covered diverse topics including noisy motorcycles, consumer and industrial product noise, and noise control engineering education. Workshop reports are available for download at the INCE-USA website, at https://www.inceusa.org/publications/technical-reports/

Recent workshops are member-initiated events, with workshops proposed to the National Academy of Engineering by an NAE member. In past years, George Maling represented the bridge to the NAE, and since his passing earlier in 2021, this responsibility has been assumed by NAE member Eric Ducharme, a former chief engineer with GE Aviation. We are fortunate to be joined and supported by Ducharme, who is scheduled to provide welcome remarks on the workshop's second day.

In addition to Akay himself and Ducharme, workshop organizing committee members also include Purdue University professor Patricia Davies; Robert Hellweg of the consulting firm Hellweg Acoustics; Eric Wood of the consulting firm Acentech; and Gregg Fleming with the U.S. Department of Transportation's Volpe National Transportation Systems Center. The organizing committee extends its gratitude to several individuals and organizations for their support of the TQA workshop series, including John Anderson, NAE president and executive officer; and Alton Romig, NAE executive officer who is also serving as the academy's chief operating officer.

The NAE provides a meeting space for in-person workshops and much more. For example, the academy provides valuable technical and organizational assistance for workshops including virtual meetings such as the current one. In particular, thanks are extended to Sherri Hunter, NAE meetings coordinator, and Ahmir Robinson, who facilitates the meetings' technical aspects. Financial support was provided by the International Institute of Noise Control Engineering (I-INCE) and the INCE Foundation.

Last but not least, the speakers and additional participants represent the crucial core of the workshop by sharing their specialized expertise. "The steering committee thanks every one of you for your participation and contributions to this workshop. Thank you for accepting our invitation."

SAPIENZA UNIVERSITÀ DI ROMA

The next speaker, the NAE's Alton Romig, will welcome participants on behalf of the academy. He has held diverse important positions in the fields of aerospace and defense, contributing during his career to groundbreaking projects in the government, industry, and nonprofit sectors alike.

3.2 Workshop Welcoming Remarks—Day 1

Alton D. Romig Jr. –National Academy of Engineering

On behalf of the National Academy of Engineering, NAE executive officer and chief operating officer Alton Romig welcomed workshop participants from various countries to the "Noise Around Airports: A Global Perspective" workshop. Romig, whose long career focused on aerospace and defense, noted that this workshop continues discussions on the theme of aircraft and airport noise that was the subject of several recent TQA workshops.

Military aircraft are very noisy compared with commercial airplanes, and airports that serve both types of aircraft tend to be much louder and have a larger noise footprint than commercial-only facilities. But noise from military aircraft is not generally a priority concern, given the mission of the armed forces, although quieting drones, which are used for missions such as conducting surveillance or carrying weapons, has been an important military objective.

As quieter commercial aircraft have been developed and takeoffs and landings have become less noisy, one significant benefit has been the lifting of some airport curfews. By expanding the hours of aircraft operation at airports, reducing curfew hours can substantially reduce disruptions of people's travel schedules. Further quieting aircraft so that takeoffs, in particular, and landings can occur without troublesome noise will allow for further reductions in airport curfews.

Projects focused on aircraft engine technology promise to decrease airplanes' noise while increasing efficiency. For example, aircraft such as the Airbus A320neo use Pratt and Whitney geared fan engines, which both reduce noise and improve fuel economy. The turbine speed and fan speed are controlled independently, with the fan running at about one-third the RPM of the turbine. The optimized turbine's improved fuel economy is due to a greatly increased compression ratio, and noise is reduced as the fan blade tips no longer move at supersonic speeds, allowing even larger fans and bypass ratios and further improving fuel economy. Other projects are being undertaken by GE and Rolls-Royce, among others, to quiet aircraft engines.

In addition, driven by military application, the concept of a "third stream" in an aircraft engine is an exciting possibility to support optimization of both engine thrust and fuel economy by allowing adjustments in bypass air depending on flight conditions. Adaptation of this approach may contribute to noise reduction.

A further opportunity is the notion of an open rotor in the context of both air frames and engines, which is being explored to improve an aircraft's fuel efficiency. It is worth considering how this type of open rotor will affect noise.

To students in undergraduate or graduate programs in related areas, approaches for mitigating aircraft noise represent an important area of focus going forward. "You will have a very exciting career like many of us have had in the world of aerospace," Romig said in concluding his welcome remarks.

NATIONAL ACADEMY OF ENGINEERING

3.3 Workshop Welcoming Remarks—Day 2

Eric Ducharme—National Academy of Engineering

On the second day of the "Noise Around Airports: A Global Perspective" workshop, NAE member Eric Ducharme welcomed attendees of the NAE- and I-INCE-hosted meeting, recognizing the diverse, global representation of stakeholders and interested parties and the truly global perspective to be addressed relating to aviation noise.

Aviation noise is a key environmental consideration within the broader issue of aviation sustainability. Considerations in this context include the topics of global climate impact of carbon dioxide emissions and potentially contrails; impact on the quality of life around airports, including on local air quality in terms of nitrogen oxide, and particulate matter emissions; airport noise as captured by regulatory certification measurement points at approach, sideline, and flyover; and community experience and response. Additional considerations include en route noise and cabin noise.

It is important to recognize the clarifying and enabling role of international standards and regulations from the International Civil Aviation Organization (ICAO) (alongside regulations from the Federal Aviation Administration (FAA), the European Union Aviation Safety Agency (EASA), and other national organizations). Consistent, harmonized international standards help manufacturers with issues such as product strategy; technology investment; and cost considerations for development, validation, certification, and demonstration of compliance. And consistent standards can help operators that are challenged to comply with location-dependent variations in regulations, curfews, fees, fines, and other restrictions

To live up to their promise in supporting industry, international standards must be responsive to the continually evolving expectations of local communities across the globe. People living in these communities wish to enjoy the societal benefits of aviation while maintaining their quality of life in terms of noise and other environmental concerns.

ICAO standards for transport airplanes have become increasingly stringent. Standards were virtually nonexistent until 1972, when the organization's Chapter 2 Noise Standard took effect. It covered aircraft including the Boeing 727 and the Douglas DC-9. In 1978, Chapter 3 became the new standard, in effect, for aircraft like the 737 Classic. Then, in 2006, Chapter 4 brought with it a 10 EPNdB improvement in cumulative noise criteria, which is a sum of the levels measured at three positions, versus Chapter 3, for aircraft including the Boeing 737 NextGen, 767, 747-400, and Airbus A320. From 2017 through 2020, Chapter 4 (Stage 5), represented a 17 EPNdB improvement relative to Chapter 3 criteria. (The average reduction at the three measurement positions is 5.7 EPNdB from Stage 3 to Stage 5; however there could be large variations in the measured reductions between the three positions.) Stage 5 covers aircraft such as the Boeing 777, 787, 737 MAX, Airbus A380, A320neo, and A350. In spite of these increasingly stringent international noise standards, local standards have also emerged for some high-traffic airports around the world such as London's Heathrow, Gatwick and Stansted, and Tokyo's Narita—raising challenges for the aviation industry.

Meanwhile, industry, government, and academia have all been very focused on reducing noise. Associated technologies deployed and under development include those aimed at reducing noise at the engine source: higher-bypass ratio or lower-pressure ratio turbofans; turbomachinery designs that are cut off relative to acoustic tones, nacelle acoustic

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treatments, exhaust nozzle chevron, etc. Some technologies deployed and under development aim to reduce noise at the aircraft source: the aircraft aerodynamic noise, the vortex shedding from bluff bodies, and the edge noise sources from gaps, corners, deploy flaps, and landing gear.

It is worth noting that, during the approach and landing phase of flight, airframe noise in modern airplanes typically contributes more to noise levels than engine noise, although this is not the case during takeoff. Other sources of noise include auxiliary power units (APUs), cabin pressurization systems, propellers and helicopter rotors, and ground support equipment.

A broad, balanced examination of noise abatement requires a consideration of not only source noise and the use of abatement technologies, but also of airport land use management, noise abatement procedures during flight, and curfews and other operating restrictions. The FAA has actively participated in the development of noise-reducing technologies and in efforts to understand and abate noise.

Airport noise is the most significant public issue for the FAA. The agency engages with communities through the FAA Noise Survey, adoption of noise annoyance research on topics such as the Schultz Curve, and development of 24-hour day-night noise metrics. The FAA maintains a noise complaint system on its website. Eight U.S. locations—including New York, Boston, San Francisco, Los Angeles, and Chicago—are responsible for about 95 percent of complaints made on the FAA noise complaint system website.

Additional emerging aviation-related noise issues include the impact on noise of performance-based navigation (PBN) and the effect of concentrating traffic patterns into particular flight paths and neighborhoods; the issues associated with advanced air mobility; and renewed interest in supersonic flight.

In conclusion, these types of topics to be covered during the "Noise Around Airports: A Global Perspective" workshop will make for an "excellent program." The workshop organizers are appreciative of attendees' engagement on this important area of focus.

3.4 Workshop Welcoming Remarks—Day 3

Robert Bernhard—I-INCE

Robert Bernhard, I-INCE president, who is winding up his three-year term in the position, welcomed workshop participants on the meeting's third day, on behalf of the I-INCE board of directors. He expressed pleasure at the opportunity for his organization to co-sponsor the international workshop with the National Academy of Engineering. Noise around airports presents a challenge and represents an interesting, important topic of discussion toward achieving improvements.

For its part, I-INCE is a "society of societies," with the mission of creating a world free of unwanted sound. The organization's approximately 45 member societies and additional observers, include engineering and acoustics societies around the world with an interest in noise control engineering. I-INCE's primary activities include:

- *Annual INTER-NOISE congresses*. These conferences (the next one of which is scheduled for August 2023 in Chiba, Japan) typically host about 900 to 1,200 attendees and feature 600 to 800 papers.
- *Young Professionals Program.* This program offers the opportunity for typically 15 to 20 young people interested in noise control engineering to attend congresses and to immerse themselves in the professional noise control community to learn about a wide assortment of topics of interest to them.
- *Technical seminars.* Meetings and workshops, such as this current "Noise Around Airports: A Global Perspective" workshop, are undertaken throughout the year.
- *Noise News International.* The quarterly news magazine and online digital blog are published by I-INCE and INCE-USA to inform readers about happenings around the world in the field of noise control engineering.

The topic of noise around airports is an important international topic currently, and is expected to be into the future, as well. Drones are an example of an emerging issue in noise control engineering. With the promise of drones—in terms of efficient product deliveries, for example, and potentially as passenger vehicles that could relieve congestion in cities—come noise challenges that threaten to impede the vehicles' integration.

Thanks were extended to the National Academy of Engineering for hosting the workshop. Gratitude was also expressed to the meeting organizers for offering this workshop as a global event, despite the various time zones involved and other challenges of a worldwide forum.

In closing, I-INCE president Bernhard remembered the late George Maling, touching on the extraordinary opportunities he had to work with Maling, an "awesome," "efficient," and "effective" mentor and sponsor. These remarks are covered in greater detail in the dedicated report section highlighting George Maling's standout contributions to the field of noise control engineering, including his invaluable role in the NAE *Technology for a Quieter America* consensus report and follow-up workshops such as the current one about noise around airports.

3.5 Workshop Welcoming Remarks—Day 4

Guru Madhavan—National Academy of Engineering

Guru Madhavan, NAE Norman R. Augustine Senior Scholar and the academy's senior director of programs and director of the Forum on Complex Unifiable Systems (FOCUS), welcomed workshop participants on the meeting's final day, which focused on relevant technology considerations.

While the concept of complex systems in research and practice has been recognized for nearly a century, the state of knowledge and practice in the design and management of complex systems continues to evolve. The term "unifiable" in FOCUS operates with a mindset of integration, though, the lens of interdependencies and adjacencies as brute-force integration in complex adaptive systems is not possible in design without adverse consequences. Using systems engineering as a conceptual base, the FOCUS program explores the perennials and frontiers of complexities relating to health, security, democracy, urbanization, infrastructure, the economy, and the environment. The goal of this workshop in seeking global perspectives on noise around airports, much like the goal of the FOCUS program, is to emphasize the need for improved engagement with complex systems. Importantly, this entails planning for inevitable surprises.

One example, from a decade ago, relates to Japan's electric grid that stalled in its recovery from the triple disaster of an earthquake, tsunami, and nuclear accident at Fukushima. While the afflicted northeastern parts of Japan operated on German generators at 50 Hz, the unaffected southwestern regions were powered by American generators running at 60 Hz. This profound incompatibility led to a profusion of disruptions felt worldwide, with barriers to power transfer exacerbating the aftereffects of the triple shock.

With Japan's sudden inability to manufacture and export critical engineering parts for motor vehicles, global automotive supply chain operations ground to a halt in many countries. As in this case, increasing reliability on software sensors and other electronics has increased the likelihood that a concentrated failure in a region can spread swiftly and create a widespread calamity.

The vision of a current problem often links to complex problems of the past, and a tendency exists to revert to tactics used for a previous emergency even when current circumstances are very different. For example, the response to the Chernobyl nuclear disaster was too often used to try to mitigate the effects of the materially—and consequentially—dissimilar Fukushima disaster.

Such nexus scenarios create a confluence of disparate time horizons, competencies, cultures, and perspectives. As the physical and chemical process of phase transition illustrates, something with one set of properties can transform into a very different state with a disparate set of impacts. Such information complexity can directly impact the ability to decipher the so-called "state of the system."

Looking at private-sector aviation manufacturing, for example, Boeing had to revamp its approach to the production of the 787 Dreamliner after facing numerous delays due to fragmented supply chains. Without knowing whom their suppliers were beyond the first tier, the company could not adequately diagnose or manage delays. Airbus faced similar assembly issues, with some A380 cables

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being too short due to a lack of integrated design processes across suppliers, including the use of incompatible Computer Aided Design packages.

This workshop, like previous workshops in the TQA meeting series, includes an exploration of fragmentation issues and associated risks and uncertainties. These can be linked back to the issue of unamiability: What are the implications of these dynamics? How can the systems that serve us be engineered and enhanced—preferably, for a less noisy world? One presentation recognized that "aviation noise is not only an engineer's business." And another focused on working with communities around airports when planning for changes. These considerations align with the NAE's thinking, which not only emphasizes *engineering* for people, systems, and culture, but also critically emphasizes the people, systems, and culture of engineering for making the profession more welcoming to a broader set of participants, perspectives, and philosophies.

It is important to the NAE to strongly reinforce that engineering is linked with not only technology, but also sociology. With NAE president John Anderson, presenter Madhavan has written that engineering's past was grounded in the industrial revolution and its future must be rooted in inclusive evolution. "This workshop series has been successful primarily because it has long recognized that technology and sociology are inseparable where a subject like noise control is concerned. I would like to appreciate the organizers and participants for the devoted work that makes the series such a valuable contribution to the NAE, to the engineering profession, and importantly to the global communities we serve."

4.1 George C. Maling's Contributions to the NAE *Technology for a Quieter America* Consensus Report and Workshops

Eric W. Wood—Acentech

Eric Wood and other meeting participants paid tribute to George C. Maling, a giant in the field of noise control engineering who left an extraordinary and unique legacy both professionally and personally.

As an introduction to this session memorializing George Maling, Eric Wood briefly discussed some of Maling's exceptional contributions to the field of noise control engineering, with a focus on his contributions to the NAE's *Technology for a Quieter America* consensus report and the workshops that followed from that groundbreaking document.

Maling was appointed in 2006 to chair the NAE study leading to the *Technology for a Quieter America* (TQA) consensus report published in 2010. The report is available for download from the NAE website (at https://www.nae.edu/35649/Technology-for-a-Quieter-America). He also played a lead role in 12 TQA workshops that followed from the report, which can be found on the INCE website (at https://www.inceusa.org/publications/technical-reports/).

George and his wife Norah "have been friends of mine and my wife Brenda's for decades," Wood noted. "We've had wonderful times together with both of them, and we miss George."

George Maling's son, Jeff, spoke also, emphasizing that his father did not view his noise control projects as "work," but rather "a great time" that he often shared with his good friend and colleague the late William Lang. Spending hours together on a Sunday afternoon organizing an upcoming conference, reading through a huge pile of papers, and discussing the best way to set up the meeting, was their idea of a relaxing time. "They were just tremendously passionate and that rubbed off on the whole family."

With his wife, Norah, George Maling would unpack a truck loaded with the printed proceedings from a conference, and they would send the books to libraries and individuals who had ordered them. "It was a fantastic team effort for both families. And we really benefited from seeing that level of collaboration and passion they displayed."

The airport in Santa Ana, California, exemplifies the consequential changes that have come from this kind of dedicated work in noise control, Jeff said. "Today it's amazing to see the impact the two of them had over all these years, and I say thank you, everybody, for all the recognition of that impact."

The late William Lang's son, Bob, also highlighted his memory of the profound friendship between his father and Maling. "My dad was so lucky to have a friend like George. I can't think of a day they weren't working on something together, and I don't think either of them considered it 'work.' Their friendship was actually older than me. They were lifelong friends sharing a lifelong passion, and I'm so happy to see that passion live on here."

Robert Bernhard also paid tribute to George Maling, who sponsored Bernhard's foray into fan noise projects and, far beyond that, provided committed mentorship as Bernhard learned the area. Maling helped build a fan noise plenum at Purdue University's Herrick Labs "that has served our faculty members very well," Bernhard added.

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Maling carried a huge load in his project collaborations, and his partnerships with Bernhard on INTER-NOISE and NOISE-CON projects were no exception. “It was always a pleasure to work with George. He was awesome, efficient, effective, and he really got things done.”

An example of a noteworthy achievement later in Maling’s life is his leadership role related to the NAE’s *Technology for a Quieter America* publication, which has importantly impacted noise control efforts in the decade plus since its publication. “And I really want to applaud him and the other organizers of the distinctive follow-up on that report in the form of these workshops on a number of topics,” Bernhard expressed. “The related outreach to influential parties such as policy makers is also appreciated.”

“I wanted to express a special thank you to all of you involved with the planning of this workshop,” Bernhard added, “as one of George’s last wishes was that the workshop be carried through. It struck me it would be appropriate to challenge the NAE, INCE Foundation, INCE-USA, and I-INCE to consider developing a workshop series in George’s honor to carry on this kind of workshop into "the future.”

Throughout the “Noise Around Airports” workshop, other participants took the opportunity to remark on their own professional and personal memories about George Maling. Patricia Davies remarked, “I have many happy memories of working with George. He was a true star and a great person.” Truls Gjestland dedicated his presentation to his “good friend George”.

Dedicating his own synthesis of the *Quiet Drones* (QD) symposiums for the current workshop to George Maling, Jean Tourret highlighted Maling’s influence on the QD symposia, “to which George gave his deep support, as he did for other events.” Tourret remembered Maling as “above all, one of the greatest figures of our noise control engineering community, to which he devoted a great part of his life with a permanent mix of kindness and efficiency.”

George C. Maling Jr. at Noise-Con 2011

4.2 William Lang's Contributions to the NAE *Technology for a Quieter America* Consensus Report and TQA Workshops

Robert Hellweg—Hellweg Acoustics

Robert Hellweg led remarks celebrating William Lang's professional footprint that went hand-in-hand with cherished friendships he was known for nurturing. Hellweg highlighted Lang's pioneering expertise in noise control engineering, as well as his generous financial support for the engineering organizations and endeavors he held dear.

Robert Hellweg led the workshop tribute to William Lang—describing Lang's "long and distinguished career in noise control engineering and acoustics" and spotlighting, in particular, his contributions to the NAE *Technology for a Quieter America* consensus report and the series of workshops following from the report. Lang passed away shortly after the 2016 TQA workshop on technology transfer in the noise control arena.

A memorial session dedicated to Lang was held at INTER-NOISE 2018 that delved into his diverse and remarkable contributions in acoustics and noise control engineering, and also presented a touching perspective on his personal life. The presentations at his memorial session are listed in Figure 4.2-1. A booklet titled *Honoring a Global Pillar of Noise Control Engineering: William W. Lang* was developed covering the various tributes, and these proceedings can be accessed on the INCE-USA webpage, https://www.inceusa.org/about-ince-usa/history/

At the INTER-NOISE 2018 memorial session, then-NAE president C. D. (Dan) Mote spoke about many of Lang's contributions to the academy. Lang's report to Mote titled *Unleashing the Intellectual Brilliance of the National Academies* led to the formation of the NAE member-initiated programs that have advanced the NAE mission and objectives. The recent TQA Engineering a Quieter America workshops exemplify these member-initiated programs.

Like George Maling, William Lang was heavily involved with the all of the NAE TQA efforts. He provided invaluable support, advice and expertise throughout the TQA projects and helped lead to the publication of the 2010 NAE consensus report *Technology for a Quieter America* (available at https://www.nae.edu/35649/Technology-for-a-Quieter-America).

Lang took a leadership role in the organization of the TQA-related follow-on workshops. For each of the workshops before his death, Lang was a member of both the TQA workshop steering committee and the TQA advisory board, composed of NAE members. The TQA workshop reports are available on the INCE website, at https://www.inceusa.org/publications/technical-reports/.

William Lang provided generous financial contributions in support of several noise control related projects. His benevolent contributions to the NAE made the 2010 consensus report possible, and his financial support to the INCE Foundation supported these follow-on TQA workshops by funding diverse aspects related to the preparation, printing, and distribution of the reports.

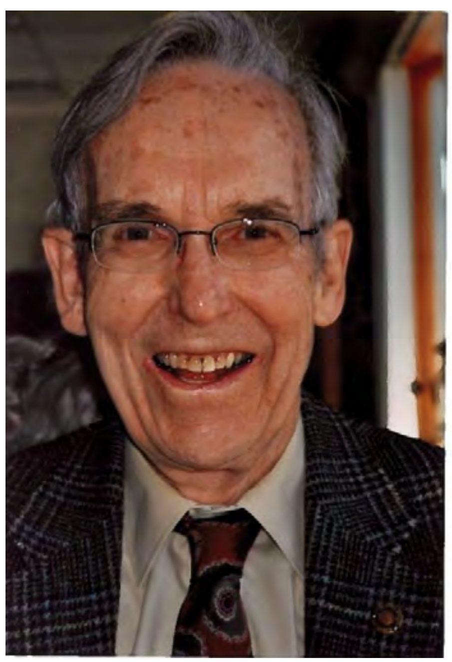
Hellweg Acoustics

"I could go on talking for hours about Bill's contributions and leadership," Hellweg said, "but I think you can see from just this short summary how important he was to the noise control field and our TQA-related activities. Thank you, Bill. It was a pleasure knowing you, working with you, and having you as a friend."

William Lang Memorial Session at INTER-NOISE 2018

- Contributions at the National Academy of Engineering - C. D. (Dan) Mote, Jr.
- Family and Personal Perspectives - Robert Lang
- Innovative Approaches in the Founding of Professional Organizations - George Maling
- Contributions to IBM Acoustics and IBM in General - Matthew Nobile
- Contributions to IBM Acoustics and IBM in General - David Yeager
- Contributions to Acoustic and Noise Standards - Robert Hellweg
- Technology for a Quieter America and Follow-on Workshops - Eric Wood
- Global Noise Policy - Tor Kihlman
- Contribution to Noise Control Engineering in Japan - Hideki Tachibana
- I-INCE - Robert Bernhard

- **PDF Booklet** "*Honoring a Global Pillar of Noise Control Engineering: William W. Lang*" **available at https://www.inceusa.org/about-ince-usa/history/**



William W. Lang
photo from INTER-NOISE 2018

5.1 Keynote Address: A Global Perspective Through 2050

Gregg Fleming—Volpe National Transportation Systems Center

The International Civil Aviation Organization's (ICAO) Committee on Aviation Environmental Protection (CAEP) conducts a global environmental trends assessment every three years, examining international trends in aviation noise as well as emissions and fuel burn. The group's sophisticated modeling, using advanced databases with worldwide scope, points to the promise of noise-neutral growth at least through 2050.

Gregg Fleming, with the U.S. Department of Transportation's Volpe Center, presented the first keynote remarks of the "Noise Around Airports: A Global Perspective" workshop. Fleming's remarks overviewed the state of airport noise internationally—currently, and projecting forward to the year 2050—with content based on the global environmental trends assessment performed every three years by the International Civil Aviation Organization's (ICAO) Committee on Aviation Environmental Protection (CAEP).

The remarks focused on noise modelling, although ICAO also addresses environmental trends in the forms of aviation emissions and fuel burn. For a detailed summary of the organizations that contributed to the environmental assessment report and elaboration on the trends he would touch on, Fleming directed attendees to the *ICAO Environmental Report 2022*, at www.icao.int/environmental-protection/Pages/envrep2022.aspx.

The driving database relating to ICAO's analysis of environmental trends is the Common Operations Database (COD), which in fact may be the most comprehensive available database of global operations. Contributors include North American Radar Data, European Radar Data, and Brazilian Radar Data. These data are augmented using a commercial source called "Flight Aware" which provides data from the Australia-New Zealand region and a few additional countries. When radar-quality data are lacking, the Official Airline Guide (OAG) data can help fill in gaps.

The foundational COD for this workshop discussion is from 2018, which was selected because it preceded Covid and the assessment team felt it was essential to rely on a more representative global fleet to project out to 2050 rather than an anomaly in operations from a year or two post-Covid.

The second database, the Fleet Database, supports the COD and allows for computation of noise. It provides all the aircraft's performance coefficients and allows the group to compute noise from the aircraft based on in-flight performance information.

The major components of the Fleet Database are:

- *Aircraft Noise and Performance Database*. Maintained by EUROCONTROL, this database supports the computation of noise and performance for aircraft operating in the terminal area.
- *Fleet Registry*. By providing information on the aircraft tail registration number, the registry helps determine the aircraft engine combination and, in turn, maps that to the noise for that combination.
- *Base of Aircraft Data (BADA)*. This allows for the computation of aircraft performance en route.

U.S. Department of Transportation Volpe Center

- *Engine Emissions Data Bank*. This data bank allows for the computation of aircraft emissions beyond the terminal area.
- *PIANO Aircraft Performance and Emissions Database.* This commercially available tool provides an alternative approach to BADA for computing aircraft performance.

The COD itself includes about 7,900 airports globally. Given the resource-intensive nature of airport noise computation models, the investigators intelligently down-sampled to 320 so-called “noise airports” that, based on a noise energy analysis, represent about 80 percent of the global airport noise exposure in terms of population. The 320 airports, which are fairly evenly distributed across global regions, are marked with red dots in Figure 5.1-1

Another database, the Growth and Replacement Database, defines aircraft available to grow the fleet and replace retired aircraft out to 2050, filling in the fleet for future years before the information is run through noise models. Additional supporting databases include those summarized in Figure 5.1-2. The Noise Certification Database provides the foundational noise data for the computations, allowing investigators to make needed adjustments. This database includes every certified aircraft engine combination, supporting the refinement of data in the Fleet Database based on actual noise certification information. Then, in addition to computing the contour areas and actual contours around airports, the information is overlaid with Geographic Information Systems to compute population impact.

The modelling piece enters the analysis next. Fleet and operations forecasting using the Growth and Replacement Database is depicted in the conceptual Figure 5.1-3 graphic, which addresses how future fleets are generated. The graphic depicts fleet evolution by 10-year increments, with 2018 as the base year and going out to 2048 specifically, but in essence covers a range through to the outside year-of-interest 2050. Each decade, some aircraft retire, while demands within the global fleet increase. The darker blue represents the aircraft retained in service, with lighter blue representing the replacement aircraft and green representing growth in the industry.

To support forecasting, the analysis breaks the globe down into regions, as shown in various colors in Figure 5.1-4. Economic data drives the demand forecast in all the route groups, with some regions (such as North America and Europe) considered in their entirety, while other regions (such as the Asia-Pacific region, within which China has a distinctively faster-growing economy) broken down further.

In terms of noise modelling, high-level elements include the base year and future operations and three models, each of which runs certain airports: the FAA’s Aviation Environmental Design Tool (AEDT), the EASA/EUROCONTROL SysTem for AirPort noise Exposure Studies (STAPES) tool, and the UK Civil Aircraft Noise Contour (ANCON) tool. The analysis breaks up the 320 airports, runs them across the modelling suites, and generates population exposure as well as contour area.

The metric of interest is the day-night sound level (DNL). Annual average day (AAD) operations are computed from COD for each of the 320 airports. Additional assumptions are listed as inputs on Figure 5.1-5. The Society of Automotive Engineers SAE Aerospace Information Report AIR 1845 special atmosphere in the document was generated by averaging data from many global airports. And this atmosphere was used to compute atmospheric absorption.

DNL contours are generated for DNL 55, 60, and 65 dB. Population contours as well as area counts can be included. Once each of the 320 airports is run across the relevant noise models—with some run across the three tools to verify consistency—numbers are aggregated up to the regional level and in turn aggregated up to the global level.

The two fleet evolution models used are the FAA Fleet Builder, for input to AEDT, and the EASA/EUROCONTROL's aircraft assignment tool (AAT) for input to ANCON and STAPES. Quality control measures are in place to ensure the results from the two fleet evolution models are consistent with each other.

Results were computed for base year 2018; for 2020, 2024, and 2028; and then in 10-year increments (but going straight to 2050 rather than 2048). The reason for the short intervals between the early analyses was to capture the Covid recovery curve.

The baseline scenario basically assumes no new technology—that is, that the fleet is simply rolled over out to 2050—which will not be the case. This and three additional scenarios, all of them based on analyses of historical data and developed in close collaboration with technology experts within the ICAO CAEP, are summarized in Figure 5.1-6. As shown, the per annum improvements range from 0.1 to 0.2 EPNdB depending upon scenario and these values represent a cumulative improvement at three noise certification measurement points. Scenario 3 assumes a Covid delay, with no new technology improvement from 2019 to 2023.

Results are shown in Figures 5.1-7, 5.1-8, and 5.1-9. Figure 5.1-7 shows the contour area with noise levels above 55 dB DNL. (DNLs of 60 and 65 were also generated.) The lines between the sliver graphics represent the four scenarios, with the solid blue line marking the baseline scenario, with no technology improvements. The dashed lines represent low technology improvements, advanced technology improvements with a Covid delay, and advanced technology improvements with no Covid delay.

The analysis attempts to capture the Covid dip from a noise standpoint. The triangle marks the last CAEP work cycle's 2015 model point. The analysis shows that, with expected technology advances, a noise-neutral growth scenario is possible from a global perspective.

In another way of representing the graphic, Figure 5.1-8 shows the contour area normalized to 2018. Assuming the most aggressive technology improvement, a slight reduction is seen as soon as 2025 or 2026 in noise relative to 2018.

And Figure 5.1-9 shows the 55 dB DNL contour for the 320 airports, overlaid with population. While not quite noise neutral, the most advanced technology scenario results in a fairly flat line in terms of population noise exposure. With tens of millions of people impacted by this noise level, a continued noise challenge is anticipated into 2050, but it is important to acknowledge that advanced technology is expected to keep up with increases in noise.

In terms of this encouraging message that noise-neutral growth may be achievable at least through 2050, it is notable that this is true even given the environmental trends assessment is based primarily on legacy tube-and-wing aircraft. An examination that assumes vast changes in design—for example, a hybrid wing—could raise the possibility of even greater noise improvements.

The ICAO CAEP continually examines its standards that underlie its noise modelling. Advances currently under consideration include a better approach for accounting for reduced-thrust takeoffs. Once a method is agreed upon, models will be harmonized and algorithms refined.

Government investment is necessary to help improve technology readiness levels, and research funding from U.S. government agencies such as NASA and the FAA could bring new designs to aviation that help make the aggressive noise control scenarios a reality.

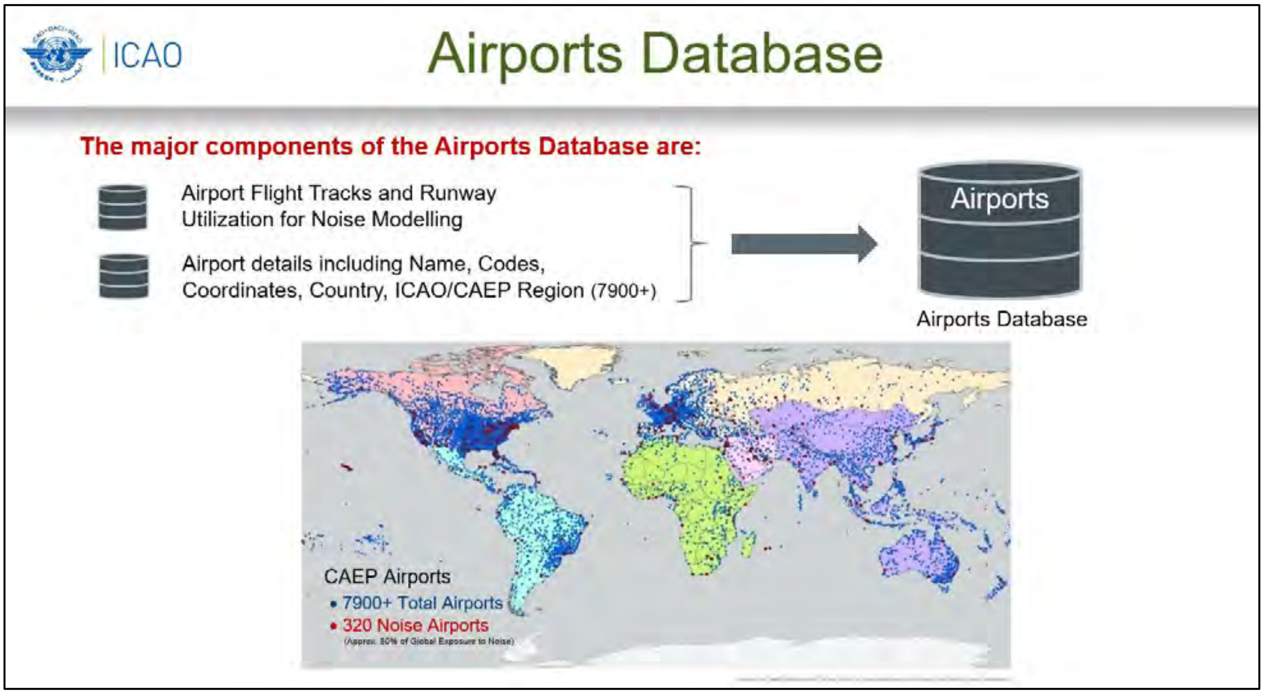


Figure 5.1-1 *The 320 "noise airports," narrowed down from 7,900.*

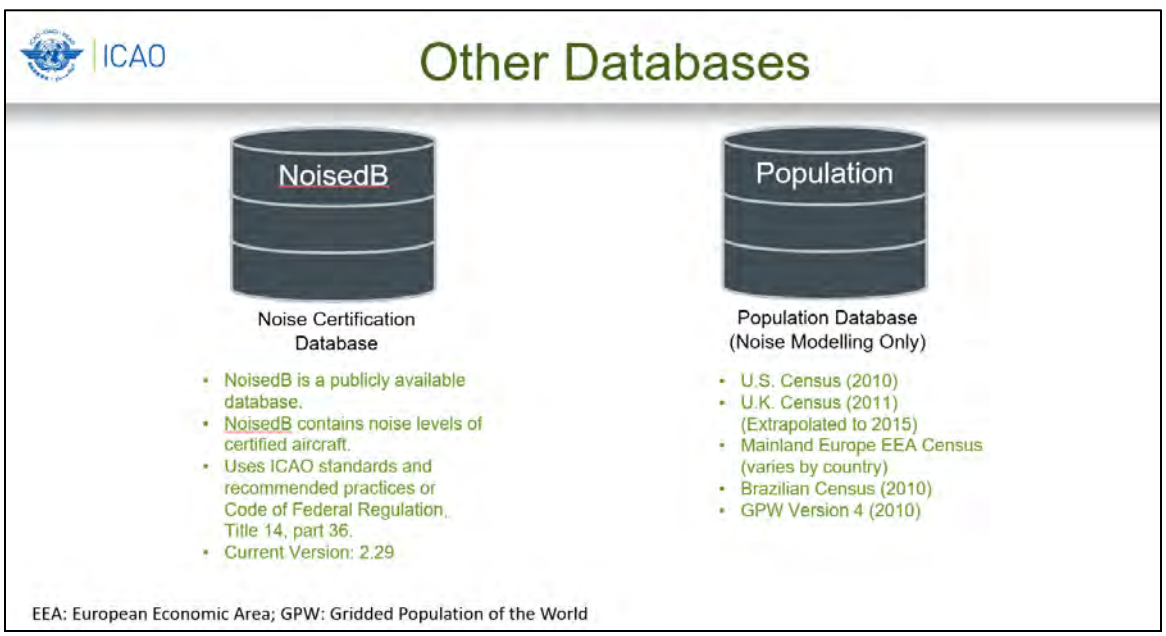


Figure 5.1-2 *Databases beyond the Growth and Replacement Database.*

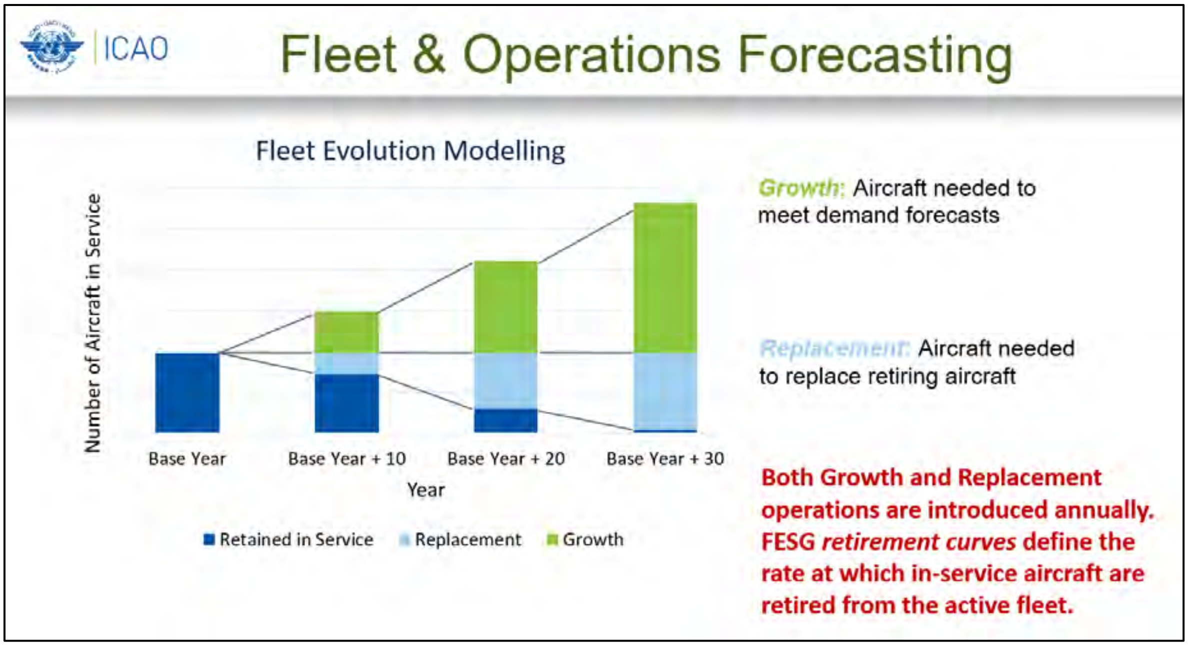


Figure 5.1- 3 *Future fleet forecasting using the Growth and Replacement Database.*

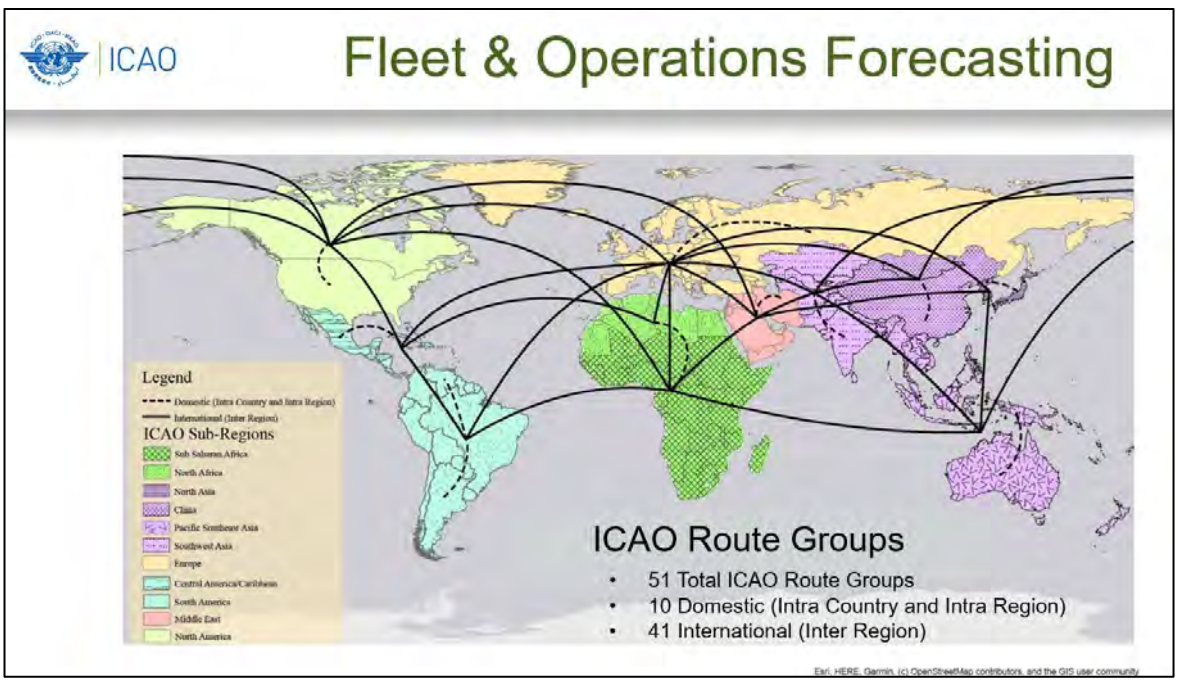


Figure 5.1-4 *Forecasting undertaken based on region.*

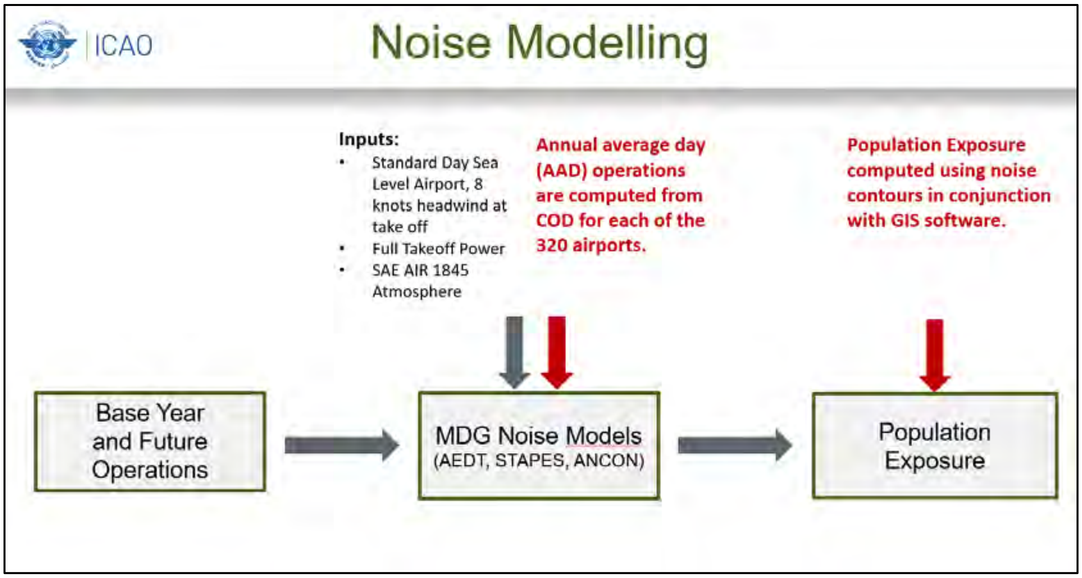


Figure 5.1-5 *Noise modelling assumptions.*

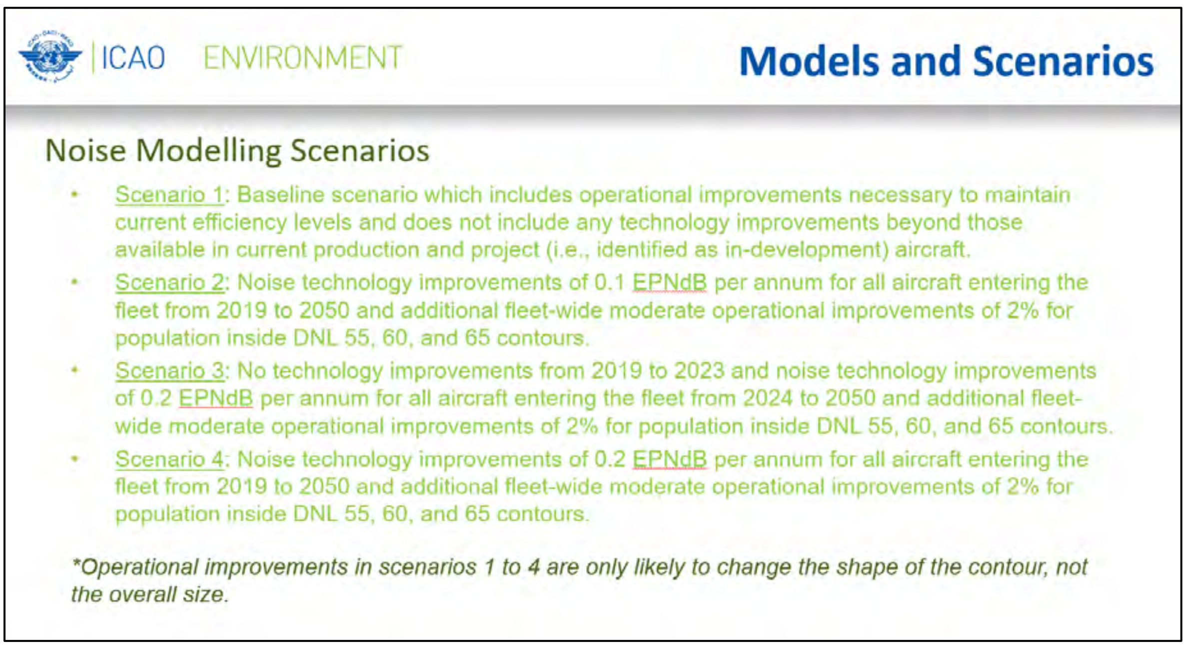


Figure 5.1-6 *Scenarios based on varying degrees of technological advancement.*

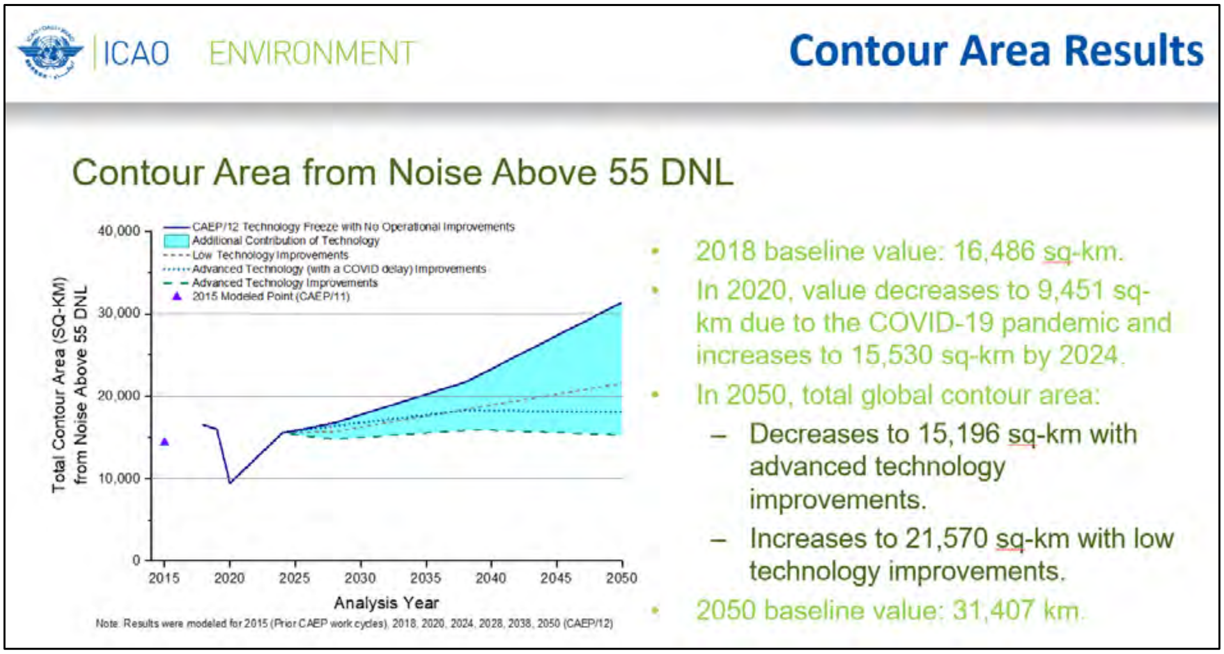


Figure 5.1-7 *Contour area results: Noise level above 55 DNL.*

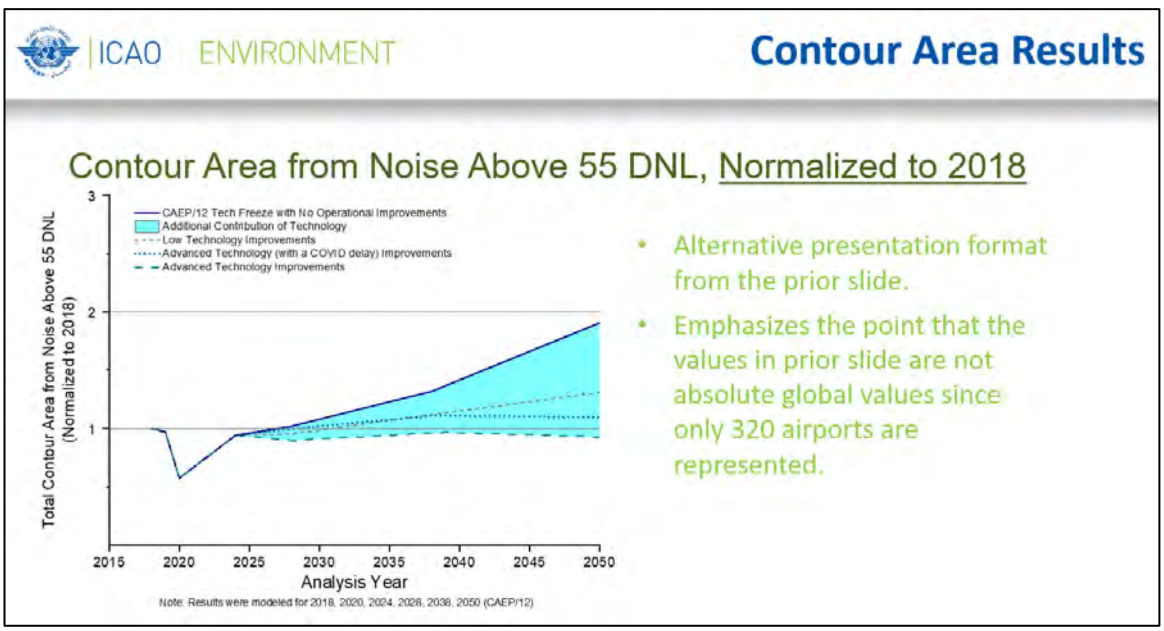


Figure 5.1-8 *Contour area results: Noise level above 55 DNL normalized to 2018.*

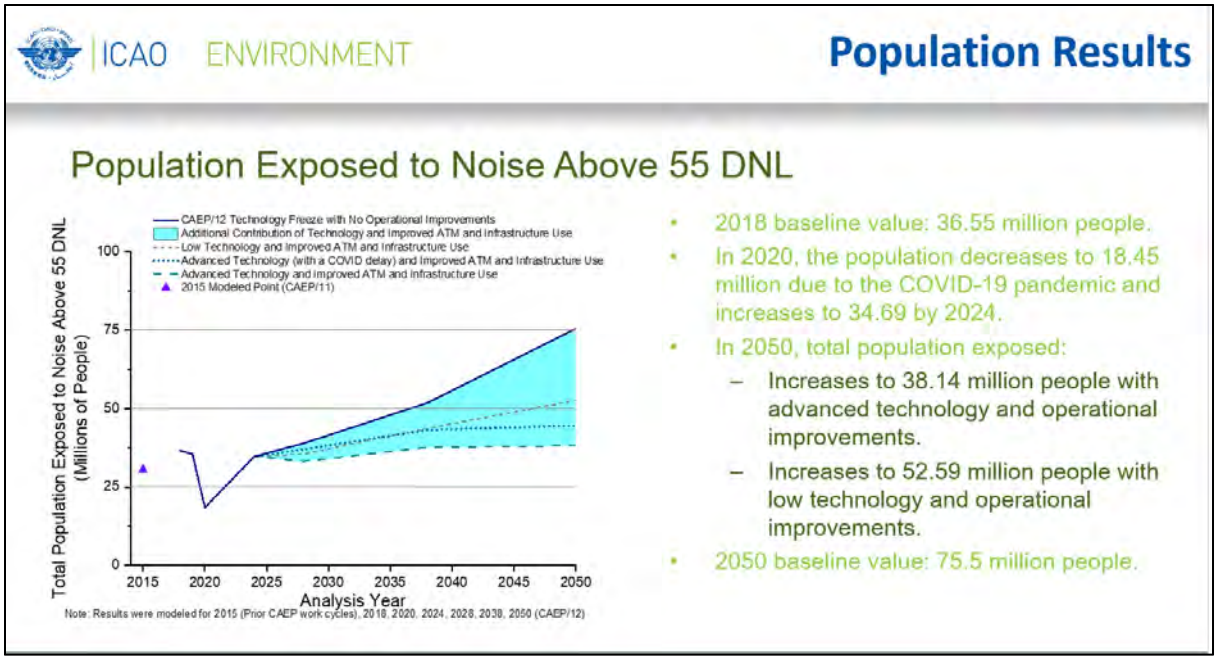


Figure 5.1-9 *Population exposed to noise above 55 DNL*

5.2 Noise Situation at Australian Airports

Marion Burgess—University of New South Wales

In Australia—which covers a vast space that increases reliance on aviation for transport—various measures are in place to mitigate noise affecting communities around airports. Noise assessments are required as an airport develops or updates its master plan, for example. National air navigation service provider Air Services Australia has developed flight path design principles that include noise abatement measures. The organization also undertakes community consultation and provides extensive information to the public about noise and flight path data. An independent aircraft noise ombudsman investigates noise complaints and recommends corrective measures as necessary.

Marion Burgess, Honorary Associate Professor at the University of New South Wales, Australia and a researcher with the School of Aviation, spoke about aviation noise in Australia. Given the continent's vastness and distance from other parts of the world, air travel has become the primary means of transportation both within Australia and internationally. The country has ten major airports, with seven of them situated along the eastern coast where the majority of the population is located. Before the pandemic, the Sydney-Melbourne route of about 700 kilometers was the top domestic route, with around 10 million passengers annually. International routes served nearly 4 million passengers per year. Airports are continually expanding and adding runways to meet the increasing demands.

In terms of noise, assessments are required for any new airport and when changes are made to an existing airport's master plan—a document that covers a 20-year strategic vision, including environmental impacts, and also presents an environmental strategy over the shorter term of five years. Master plans are managed by the Department of Infrastructure, Transport, Regional Development, Communications, and the Arts.

For operating airports, responsibility for overseeing noise management lies with Air Services Australia, the national air navigation service provider. This organization manages factors associated with flight path changes, environmental impact assessment, and the Noise and Flight Path Monitoring System around Australia's major airports.

Among its requirements, Air Services Australia has developed a set of flight path design principles that balance safety, the community, and operational requirements. Under these principles, sufficient noise abatement measures must be incorporated when any changes are made to an airport's operations. This organization is also very involved with community consultation and addresses all complaints related to airport operations.

Figure 5.2-1 lists options for noise abatement for new airports and those undergoing development. These options include technology for reducing noise at the source, operations in terms of noise sharing and noise abatement procedures, and regulation that applies to land use planning and management.

A primary measure for noise management, where airport development is concerned, is the Australian Noise Exposure Forecast (ANEF) that must be prepared as part of each airport's master planning process. The ANEF—defined in Australian Standard (AS) 2021—is similar to the National Exposure Forecast (NEF), with slight modifications. It is not an enforceable law or regulation but is designed instead as a planning support tool.

Master plans include maps with the ANEF contours, alerting town planning authorities in areas near an airport of these noise contours and also offering individuals who are considering buying a house near an airport the opportunity to research what they can expect in terms of noise.

It is acknowledged, however, that information beyond these ANEF contours is needed to adequately inform the community. Therefore, the *Standards Australia Handbook*, HB 149:2016, provides guidance for those producing information about aircraft noise. Importantly, the handbook points out that a community needs to know where aircraft fly, how often they fly, how much noise the aircraft makes in flight, how widely the noise will be heard, the current and projected noise impacts, as well as other relevant factors in the context of a particular airport's operations. When an airport in Australia is creating their master plan or five-year strategic plan, the airport provides access to these additional maps and information as ways to educate the surrounding community, beyond simply providing the ANEF contours.

A WebTrak system tracks noise and flight path data at the major airports, allowing authorities to check compliance and communicating noise levels at the monitoring locations to the community while also demonstrating to residential neighbors that government agencies are paying attention to noise levels.

Various noise mitigation measures are taken at Australian airports, including limiting aircraft to those with lower noise levels; requiring low-noise landing and takeoff procedures, such as continuous descents to minimize thrust; reducing flight path options to avoid residential-area overflights; sharing of noise in surrounding areas; and preferred runway use during certain time periods. Curfews apply at certain major airports, including the state capital cities of Sydney and Adelaide, between 11 p.m. and 6 a.m. These curfews present challenges for scheduling, particularly for international arrivals, and once in place the community is very resistant to any change.

Consultation groups are recognized as essential for maintaining communication with the community and other stakeholders. For example, the Sydney Metro Airports Community Aviation Consultation Group (CACG) is an independent committee that provides a forum for community engagement on airport planning and operations. Members represent the general public, aviation, businesses, and government.

Air Services Australia has upgraded its website in recent years to present useful information and support extensive community engagement. Tools include "WebTrak My Neighborhood," as depicted in Figure 5.2-2, to provide people with access to information about airport operations and noise levels. Monthly and quarterly reports are provided based on the noise data.

Noise monitors are placed in areas around airports utilized by defense aircraft along with civilian ones, and the community is kept apprised in advance of defense operations such as night flying or low-level flying. These steps are taken in recognition that defense aircraft can raise annoyance because of factors such as unpredictable timing. An informed community may be more tolerant of these necessary operations.

Another important aspect of community consultation and complaint management is the appointment of an independent aircraft noise ombudsman. This ombudsman conducts independent reviews of complaints and where appropriate recommends steps that must be taken to mitigate noise imposition on the community. An ombudsman's study of a new runway at Brisbane airport, for example, resulted in important new guidance about improved engagement and making crucial information available to the public in more accessible, helpful formats. "Understanding the benefits of clear and transparent communication with the community, at all stages, has been acknowledged. I think the aircraft noise ombudsman plays an essential role in the management of aircraft and noise complaints in the Australian domain."

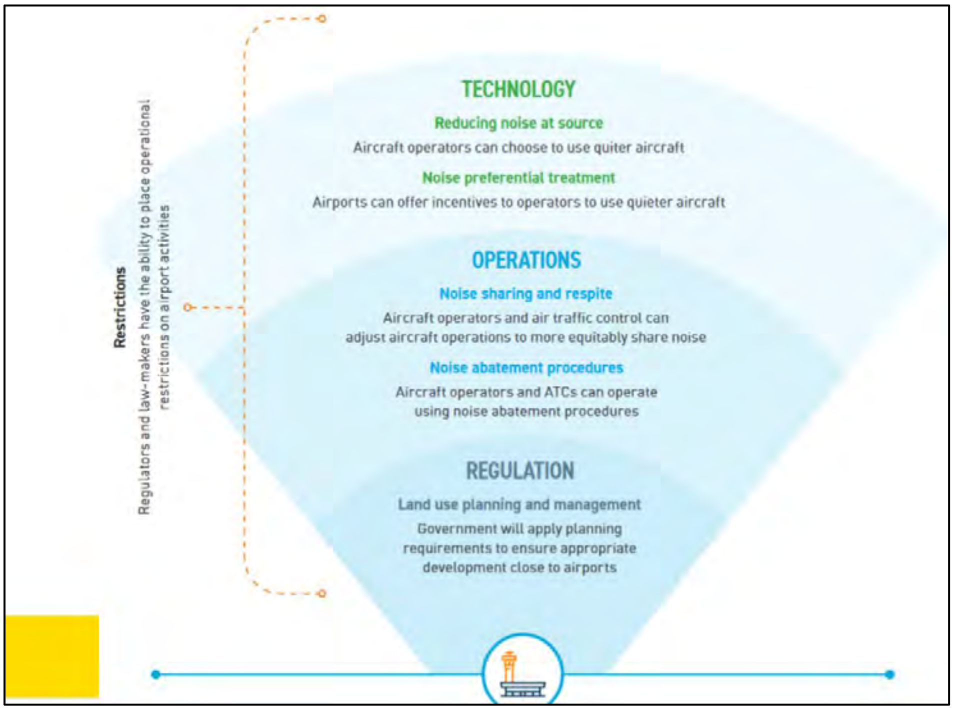


Figure 5.2-1 *Noise abatement options: Technology, operations, regulation*

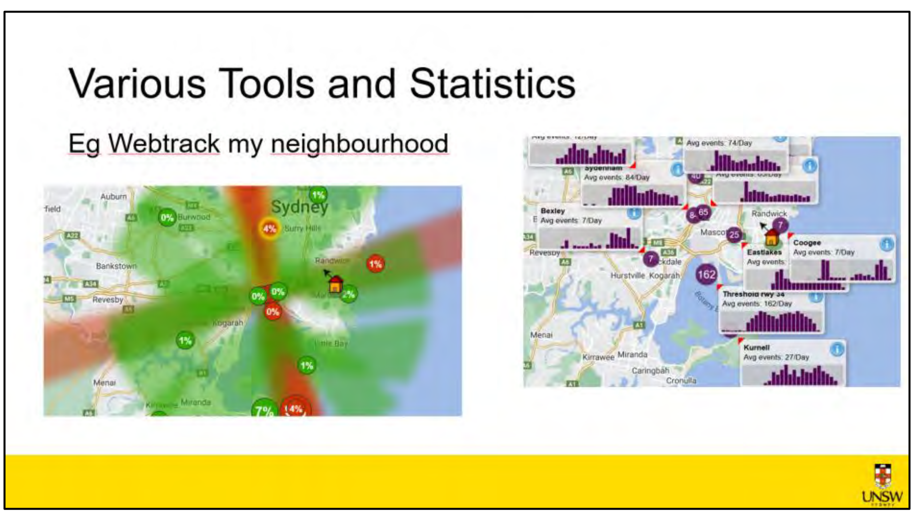


Figure 5.2- 2 *WebTrak my Neighbourhood provides information about airport operations and noise levels*

5.3 Noise Situation at Brazilian Airports

Tânia Cristina de Menezes Caldas, Ana Paula Gama, Jules Ghislain Slama, and Julio Cesar Boscher Torres—Federal University of Rio de Janeiro

The problem of noise around Brazil's airports has long been recognized and researched, but efforts must be bolstered to address community noise complaints—which are rampant and on the rise—through formal policies and effective mitigation measures.

On behalf of herself and her Federal University of Rio de Janeiro colleagues, Tânia Caldas spoke about noise issues around Brazilian airports in terms of public annoyance, current regulatory noise management approaches, and opportunities to address conflicts between airports and surrounding communities.

As a member of the International Civil Aviation Organization (ICAO) since the founding of that organization, Brazil has been working to address conflicts over aircraft noise between airports and communities. Although airport authorities have long recognized aircraft noise as a problem, issuing a decree in 1979 to regulate airport noise, practical guidelines in a formal policy have yet to be enacted to avoid conflicts that continually arise around Brazilian airports. Even when a federal law designed to help manage noise problems at airports was passed in 1982, it remained difficult to work on suitable solutions.

By 1984, noise exposure maps were developed for Brazil's main airports to spread the discussion about aircraft noise impacts. A land use compatibility plan was then discussed with local authorities willing to help prevent encroachment and control growing conflicts. The latest regulatory update in 2021 revised the Brazilian Civil Aviation Regulation (RBAC) 161, first issued in 2011. A document published in 1987 (Por. 1141/GM5) contains mainly the same guidelines.

Still, Brazil must incorporate essential tools for maintaining an effective noise management policy. The country lacks guidelines to help prevent conflicts, such as the instruments, goals, and means for applying control measures. It also falls short in terms of prioritizing and implementing actions to mitigate impacts on communities and avoid hostilities aimed at airport operations—including some that have resulted in legal actions. While conflicts have been monitored and studied by regulatory bodies and environmental agencies in Brazil, adequate measures have not been put in place to mitigate the problems.

The Brazilian Civil Aviation National Policy is designed to deal with aviation noise in Brazil, instructing that environmental aspects should be considered in aerodromes' planning, construction, and operation. In addition, the policy highlights the ICAO's resolution recommending a "Balanced Approach to Aircraft Noise Management" and was developed in alignment with the National Environmental Policy and other regulatory approaches, including the Urban Policy principles. Relevant policies are overviewed in Figure 5.3-1.

Airport noise maps are laid out in RBAC 161, which is based on the day-night average sound level (DNL) metric over 24 hours. Noise contours under this regulation focus on the percentage of people who are highly annoyed, according to the Schultz curve. This DNL metric for noise contour mapping and land use orientation is the method adopted by Brazil's National Civil Aviation Agency (ANAC). The five noise contours, each of which is associated with certain allowable land uses, are presented in Figure 5.3-2. The

65 DNL contour represents the lowest restricted noise level under RBAC 161, but it is worth noting that communities have made complaints at far lower levels.

Under an Urban Integration Program initiated in 2009, Infraero—a corporation of the Brazilian government that was once responsible for the operation of the country's major airports—developed cooperation plans with local authorities to study land use planning around airports. The cooperation agreements have considered noise and factors such as safety plans, transport integration, and bird control. In addition, the development of these plans provided an opportunity for parties to discuss various operational aspects, disclosing technical conditions to ensure safe operations.

A problem observed during engagement with the community and local authorities is that land use planning levels relied on sound level criteria considering outdoor activities and based on the community's convenience, not annoyance percentage. The equivalent sound level LAeqD and LAeqN metrics refer to daytime (7 a.m. to 10 p.m.) and nighttime (10 p.m. to 7 a.m.) levels, respectively. Most conflicts were associated with a misunderstanding of the different logic applied to analyses for noise mapping and end-user orientation. Notably, another issue is that noise insulation can be impractical for a country like Brazil due to the costs to insulate and the country's climate.

Community noise concerns continue to climb around many of Brazil's airports, and research is being undertaken to understand the level at which aircraft noise become an issue. One study examined about 22 airports' noise paths using several scenarios, including different operational conditions. Figure 5.3-3 depicts the example of São Paulo Congonhas Airport, with the superposition of a current contour and the final capacity scenario.

In recent clashes with communities around airports, claims have often focused on limitations on flight times. These communities want additional flight restrictions, including reduced weekend operations and new environmental studies, as well as an end to helicopter operations and the adoption of additional noise metrics. The communities also want to be informed by operators of the measures taken to control noise and emissions. "In our view, these kinds of demands will be repeated again and again until we establish an effective noise policy to mitigate the reported impacts and make the necessary effort to support the policy's implementation."

Santos Dumont Airport deserves mention as an example of an aerodrome with a permanent monitoring system based on demands from the community. This is one of the airports where complementary metrics were used to establish appropriate sites for equipment placement. Monitor locations—shown in Figure 5.3-4—were chosen based on areas of community complaints.

Noise complaints are submitted not only for Brazil's large airports, but also for some regional and general aviation facilities. In the case of the general aviation Jacarepagua Airport in Rio de Janeiro, noise issues have arisen from helicopter flights to and from offshore oil platforms. At some airports, authorities are working on mitigation measures such as different flight paths that cause less annoyance to surrounding communities.

Despite efforts to achieve cooperation between airports and community representatives, conflicts—including ones leading to court intervention—have been increasing, and pressure on airports and government authorities may continue to grow. Studies by the Airport Noise Study Group (GERA) and the Federal University of Rio de Janeiro, supported by the Urban Engineering Program (PEU), highlight the urgency of an airport noise management program in Brazil to address conflicts. Achieving such a program requires the identification of financial support for mitigation measures; agreement on targets, plans, and timelines; and the designation of rules for prioritizing inspection and noise control steps.

Figure 5.3-1 *Policies relevant to Brazil's regulatory approaches to airport noise*

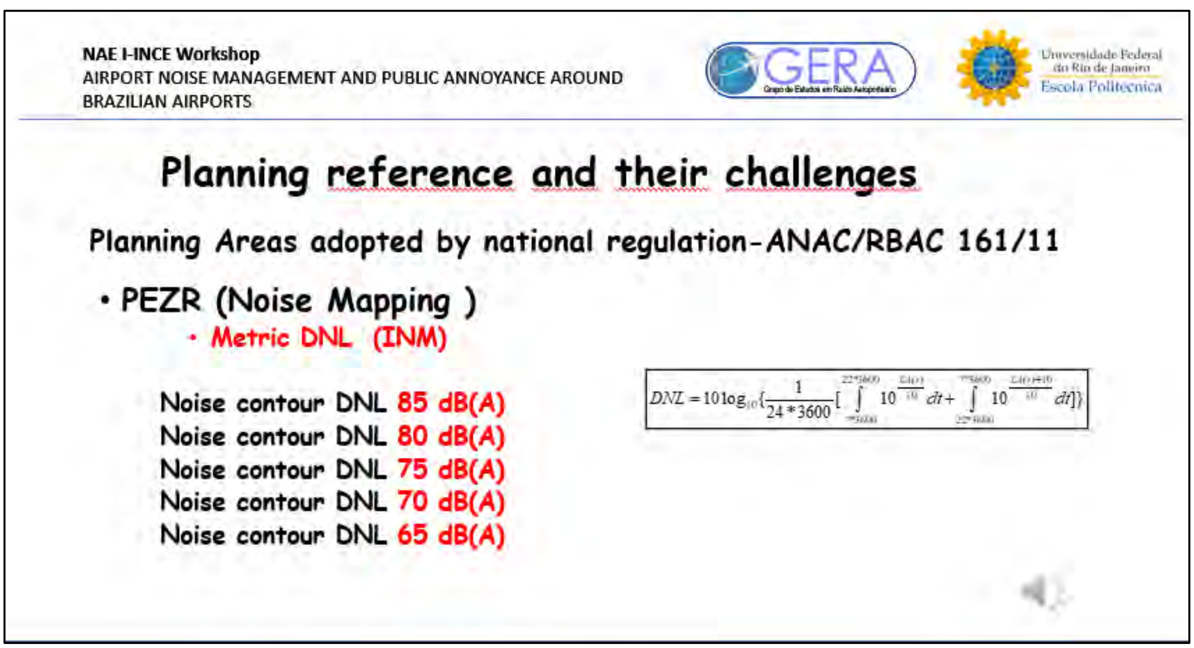


Figure 5.3- 2 *DNL noise contours associated with different land use orientations*

Figure 5.3-3 *Research into airport noise levels: Example of noise contours at Congonhas Airport*

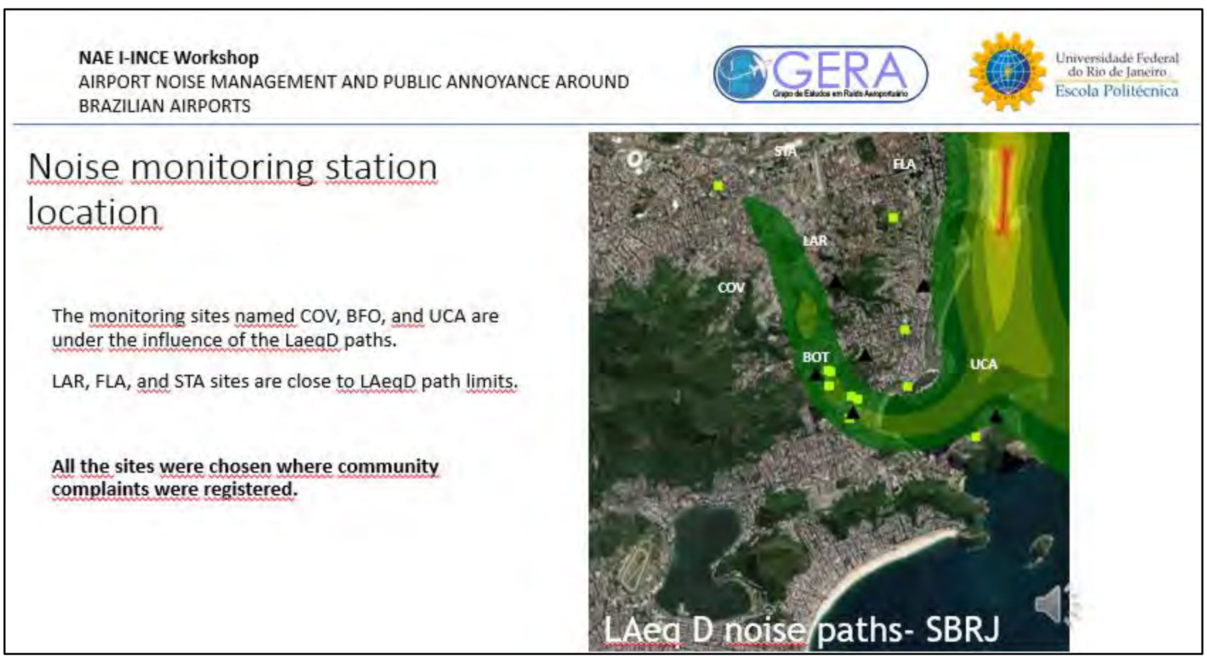


Figure 5.3-4 *Noise monitor locations at Brazil's Santos Dumont Airport*

5.4 Noise Situation at Boston Logan Airport

Stephen Sulprizio and Flavio Leo—Massachusetts Port Authority

As owner-operator of Boston Logan Airport—a major international airport located next to densely populated areas—the Massachusetts Port Authority (Massport) has developed a comprehensive noise abatement program to manage noise around the airport. Effective, ongoing efforts toward reducing noise in communities surrounding the facility include abatement steps based on an area navigation (RNAV) study by the Massachusetts Institute of Technology (MIT) in collaboration with Massport and the FAA, and a residential and school soundproofing program.

On behalf of himself and Massachusetts Port Authority (Massport) colleague Flavio Leo, Stephen Sulprizio shared his expertise on the noise around Boston Logan International Airport from his perspective as manager of the airport's Noise Abatement Office. Sulprizio focused his presentation on the operational context of aircraft-related noise around his airport. Topics included an overview of the airport's operations and overflight noise; its noise abatement program, area navigation (RNAV) study, and Residential Sound Insulation Program; and aviation noise complaints.

Boston Logan is a major international airport located about three miles from downtown Boston, adjacent to densely populated areas. Figure 5.4-1 provides additional facts about the large commercial airport.

Given Logan's urban location, Massport has developed a comprehensive noise abatement program. Among the program's key elements: noise abatement departure procedures; late-night runway preference opposite direction operations; noise emission level restrictions on runway 4L departures and runway 22R arrivals; unidirectional/wind restrictions on runway 14/32; a soundproofing program for homes and schools; engine run-up restrictions, which include limited times and specific locations within the airport; and towing requirements for certain aircraft repositioning operations.

Massport also encourages the use of single-engine taxiing and reverse thrust, and provides a 24/7 noise complaint line and near-live flight tracking on the Massport website. Also, 30 noise monitors have been positioned around the Boston area, under some of the most heavily used flight paths, to record aircraft noise on the ground.

Noise has been significantly reduced around Boston Logan since the 1980s, with the phase-out of older aircraft and the introduction of new aircraft/engine technology. The fleet mix has changed, with the Airbus A320s and Boeing 737s as the typical aircraft today, versus the B727-200s of the 1980s. Figure 5.4-2 presents an example of a single noise event in Point Shirley, the area within the Greater Boston community of Winthrop that is most heavily impacted by airport noise. As reflected in the figure, a 95 percent reduction in noise energy has been observed since the 1980s in the Point Shirley area. [Editor's note: This is equivalent to a reduction of about 13 dB(A).]

An RNAV study conducted by the Massachusetts Institute of Technology (MIT) was announced in 2016. The study, a collaboration between Massport and the FAA, arose from a large increase in community complaints after the FAA's rollout of new, more precise airspace procedures that concentrated flight paths. RNAV track concentration and community complaints in 2010 and 2017 are shown

massport

in Figure 5.4-3. In 2010, aircraft were much more dispersed and complaints more sporadic. In 2017, with more concentrated flight tracks, complaints are clustered around these concentrated flight paths.

The RNAV study analyzed ideas toward incrementally reducing noise through changes to performance-based navigation (PBN), including RNAV procedures. The study's technical approach included two categories—"block 1" over water and involving less complex procedures, and "block 2" focusing on shifting some noise to other communities and requiring more complex approaches.

The technical approach under the memorandum of understanding (MOU) between Massport and FAA is summarized in Figure. 5.4-4. Modeled noise impact is assessed using standard and supplemental metrics, and implementation barriers are assessed as listed in the figure. Procedural modification recommendations were made to Massport and its community advisory committee and the FAA. These included adjusting flight paths to move them away from populated areas and in some cases moving them over water. An MIT analysis showed a large benefit in terms of population exposure to noise from proposed changes, calculating a significant net benefit after looking at those potentially benefiting and subtracting those who would expect a disbenefit.

The Massport Residential and School Sound Insulation Program began in 1985, distinguishing it as one of the first of its kind around US airports. Eligibility is based on the FAA criterion of 65 DNL or higher. The program boasts a participation rate of about 90 percent, with treatment applied to more than 5,400 homes or 11,500 dwelling units and 36 schools. Investment from Massport and the FAA has surpassed $170 million. Along with these facts, percent of total housing units soundproofed is shown by community in Figure 5.4-5. The population exposed to 65 DNL or greater has lessened from more than 60,000 people impacted in 1980 to less than 10,000 in 2019. (A further reduction was seen in 2020, but mostly because of Covid-related reductions in operations.)

The Residential Sound Insulation Program focused on treating critical exterior surfaces such as windows, doors, and roof vents. Massport and the FAA have approved a noise exposure map, which currently uses the 2020 65 DNL contour but will reflect larger exposure contours in 2021 and 2022 based on increased operations in those years. Massport has adjusted the contours to reflect land use, as seen in the contours in Figure 5.4-6, with the solid blue line as the 65 DNL contour and the dotted blue line representing the "humanized" contour to better reflect land use in these areas. The "humanization" process is intended to extend the eligibility line to encompass connected neighborhood blocks, where practicable, rather than dividing a block.

Homes potentially eligible for insulation based on the 2020 exposure map are largely "first generation" homes—that is, homes treated in the program before 1993 (137 units across 91 properties), and never-treated homes (13 units on 10 properties). Given the high participation rate, most eligible homes other than the first-generation ones have been treated, and as the contours expand, an increase in potential eligibility is expected in terms of first-generation replacement homes.

Sound insulation control measures remained effective over years in controlling noise, according to a study conducted around 2010 that revisited treated homes. "We work hard to ensure everything is done properly and that people benefit from the program." During outreach efforts, people expressed that they were "very happy" with the program's products and results.

The numbers of noise complaints by year are shown in Figure 5.4-7. The dramatic increase from 2018 to 2019—like the increases over the entire 2012–2021 period shown—was due mostly to the implementation of an easier, online complaint system, coupled with significantly increased aviation operations in 2019. The number of complainants in the 2012–2021 time period showed a notable spike in 2017 due to some major runway closures resulting in additional noise over certain communities.

Massport provides responses and explanations to those who complain, and projects such as the RNAV study aim to alleviate their noise issues, but it can be difficult to provide relief in some cases, especially while avoiding simply moving noise to other areas.

Figure 5.4-1 *About Boston Logan International Airport*

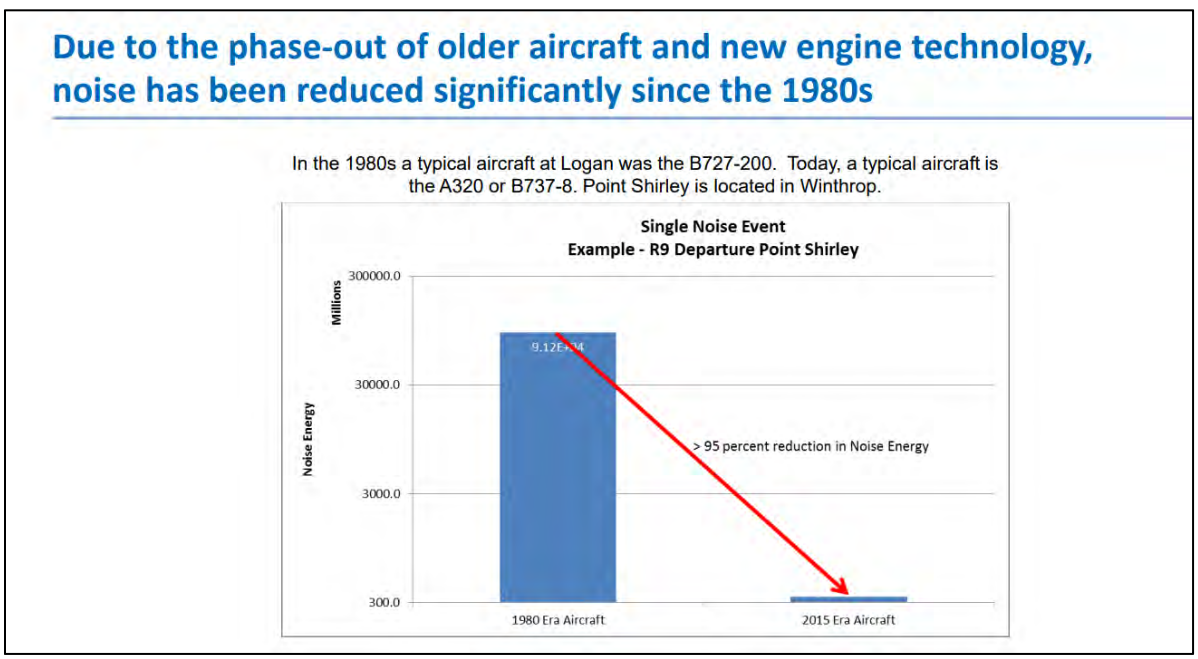


Figure 5.4- 2 *Noise reduction example—1980s versus today*

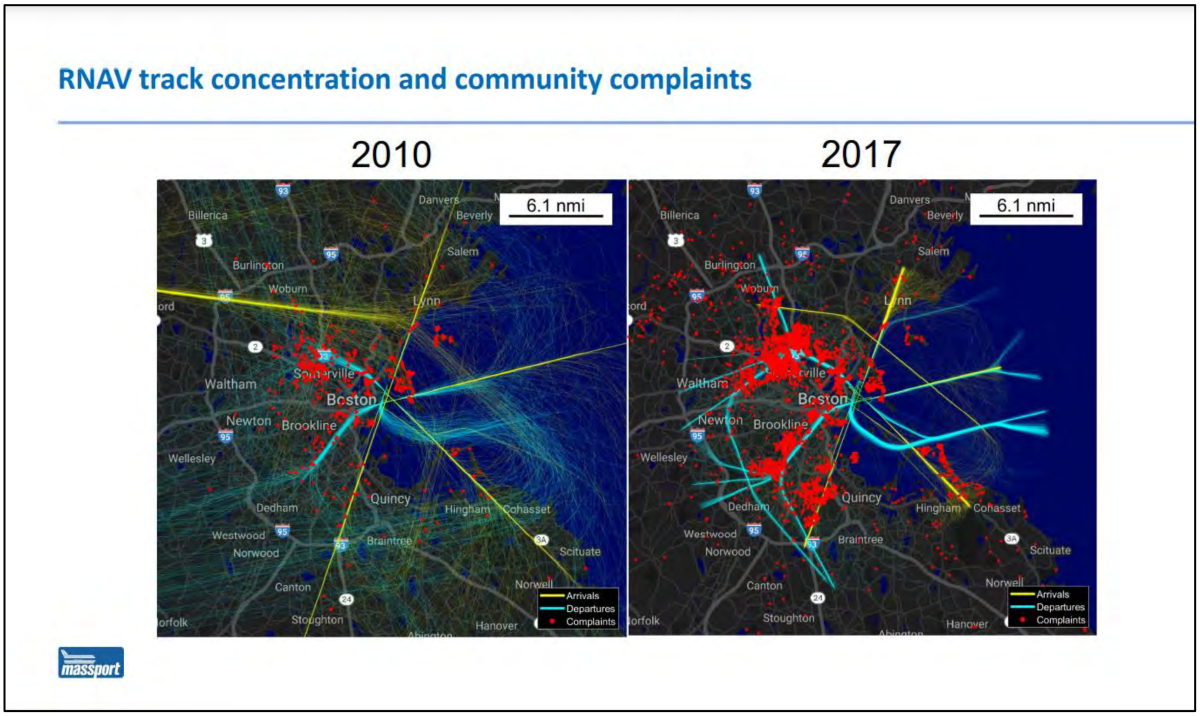


Figure 5.4-3 *Community complaints, before and after RNAV*

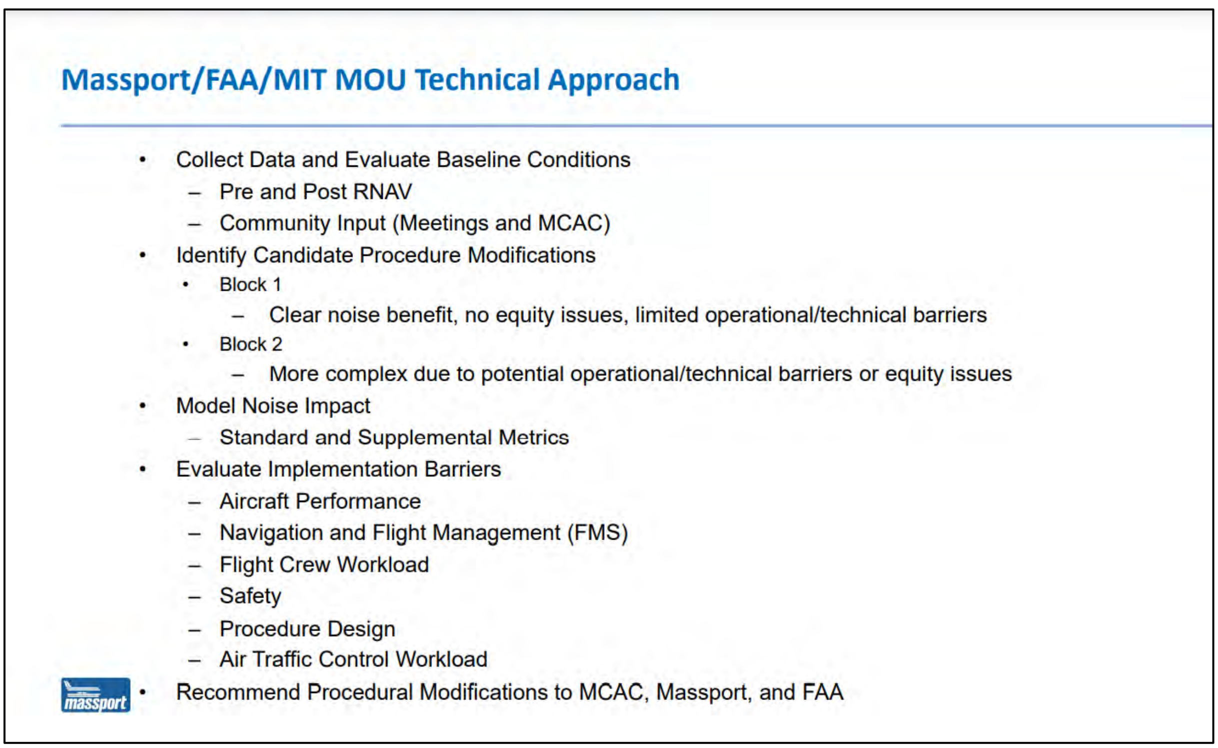


Figure 5.4-4 *Massport/FAA/MIT MOU technical approach*

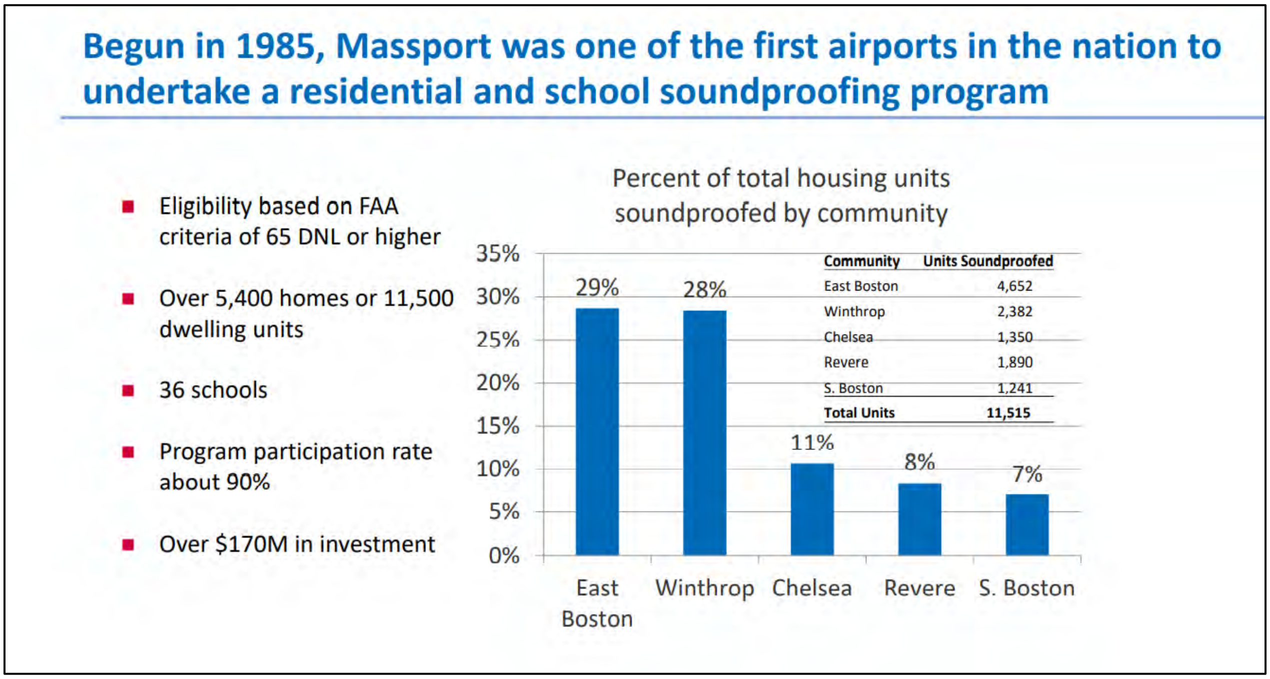


Figure 5.4-5 *Residential and school soundproofing: Representative achievements*

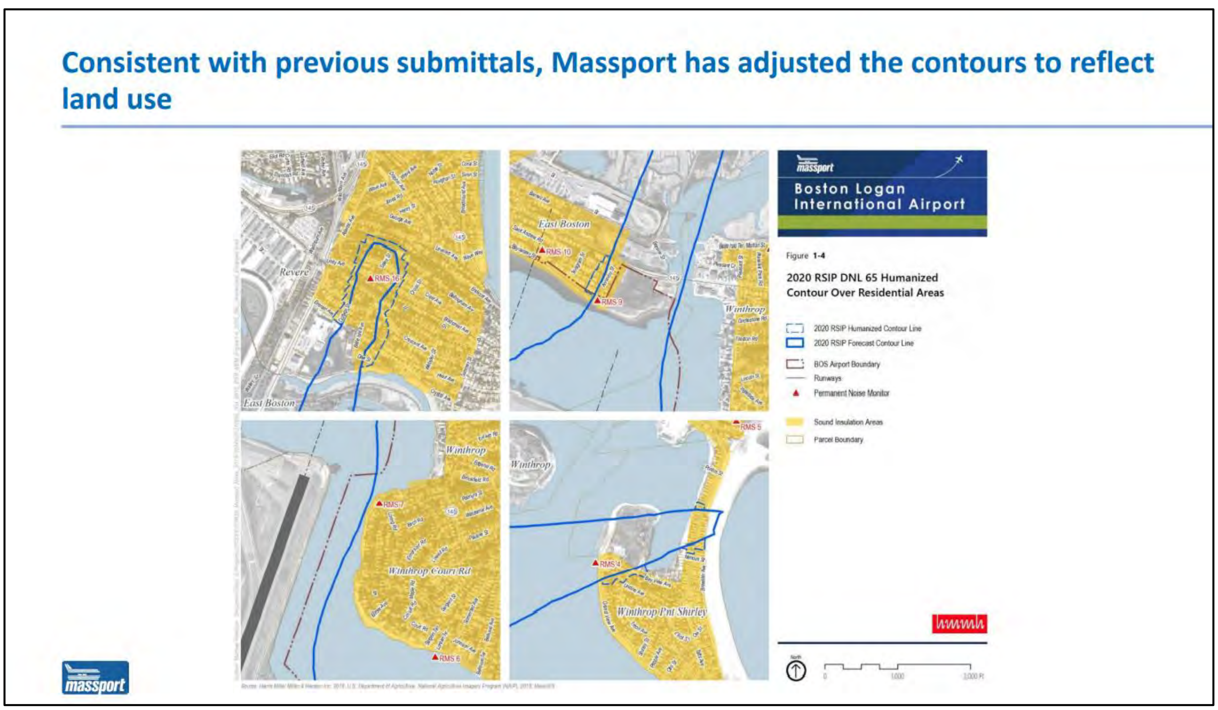


Figure 5.4-6 *65 DNL noise contours adjusted for land use*

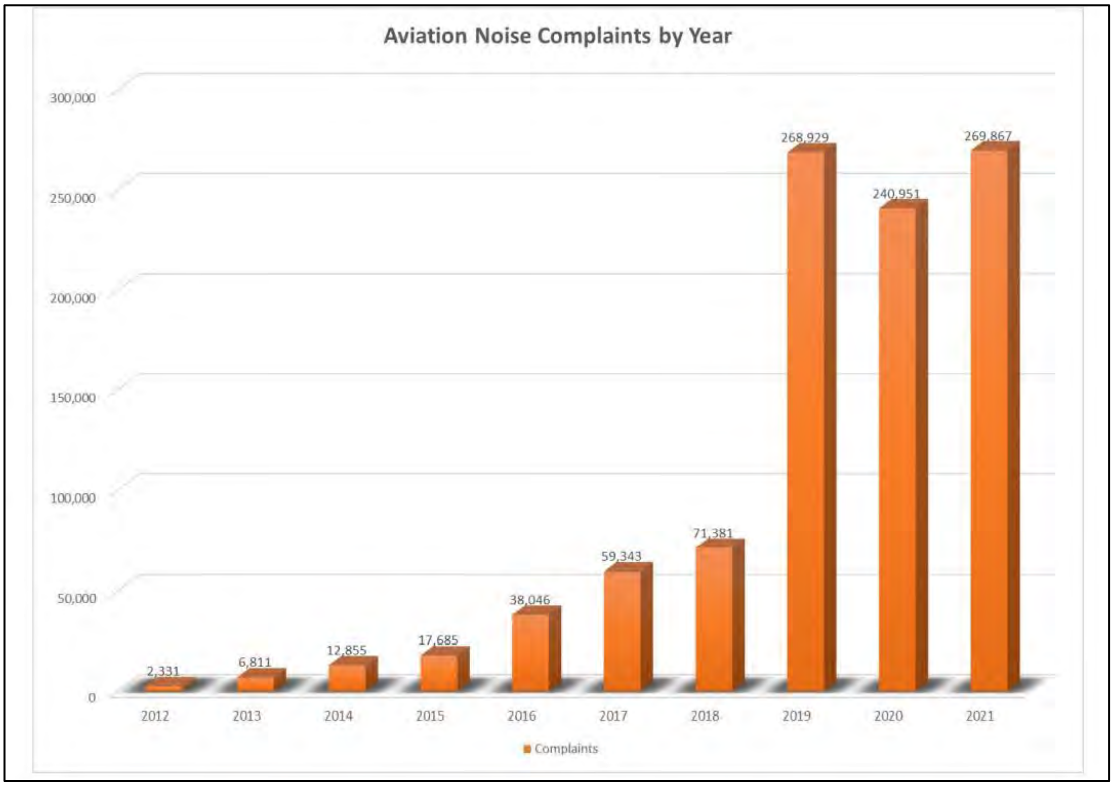


Figure 5.4-7 *Aviation noise complaints by year*

5.5 Departure Sounds From Jet Aircraft: 1959–2011

Eric Wood—Acentech Inc.

Audio files with departure noises from five jetliners introduced between 1959 and 2011 provide a sense of the marked reductions in aircraft noise achieved over the half-century.

Eric Wood demonstrated the "incredible progress" made over the years in reducing aircraft noise, by playing waveform audio files with departure noise from five jet airliners introduced from 1959 to 2011. The audio files, produced by the U.S. Department of Transportation's Volpe National Transportation Systems Center, highlight the reduction in noise over the time frame, with the recent Boeing 787 jet emitting a departure noise that is 19 dB(A) lower than the B707 of the 1950s.

Figure 5.5-1 lists the A-weighted sound levels associated with the five aircraft: the Boeing 707 (1959), Boeing 727 (1968), McDonnell Douglas MD-81 (1980), Boeing 777 (1995), and Boeing 787 (2011). To hear the sounds, readers of this report can access a PowerPoint presentation with audio samples at Volpe's website.

https://www.volpe.dot.gov/our-work/policy-planning-and-environment/jet-airliners-sampling-noise-over-time

Following are simple instructions for listening to the jetliner noise samples:

Consider turning up the volume of your speaker. After downloading and opening the presentation, select "Slide Show" mode and then "From Beginning" to see photos of the respective jets and corresponding sounds. The audio is not calibrated to a specific level and the sound naturally does not reflect that at the end of the runway at takeoff, but valid comparisons can be made in terms of relative differences in noise.

Figure 5.5-2 shows the title slide of the Volpe presentation that includes the jet audio samples. Those reading this workshop report online can click on the figure to go to the slide show, then follow the directions in the previous paragraph. And for other readers, the URL is reiterated under the figure.

Those listening to the samples may observe, as workshop participants did, that noise differences heard in the audio can seem in some cases to exceed the decibel differences presented in Figure 5.5-1—especially for the 2 dB(A) difference between the B707 and the B727. Participants posited that EPNdB values might reflect greater noise differences between aircraft models since EPNdB values adjust for tones.

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 5.5-1 *The decades have seen substantial progress in reducing noise from jet airliners*

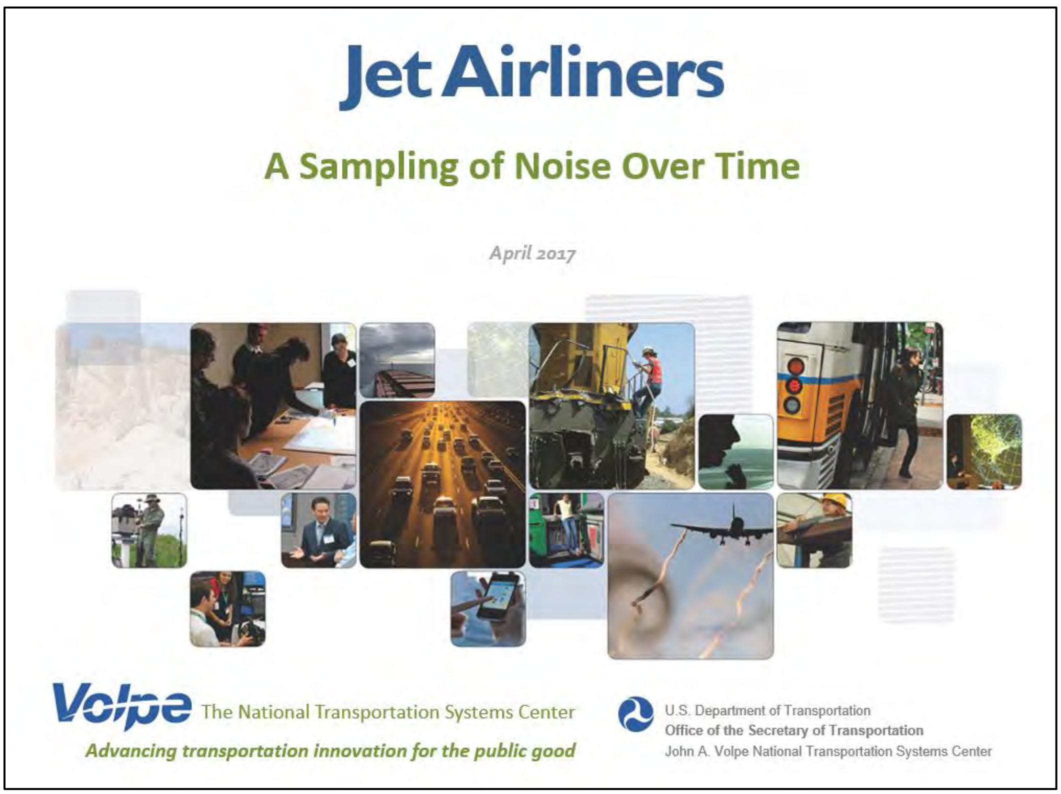


Figure 5.5-2 *Audio files demonstrating relative noise from commercial jetliners introduced over the decades are available at the Volpe website*

6.1 Keynote Address: Noise Situation at West Coast U.S. Airports

Vincent Mestre—Consultant

Four West Coast airports have the strictest noise rules in the United States, including mandatory flight restrictions. The experiences of the four airports highlight the importance of community participation in noise-related decisions, given the unique circumstances under which each airport operates.

Acoustical consultant Vincent Mestre shared his perspective on the noise situation at four West Coast airports, all of them in southern California: Santa Monica, John Wayne, Long Beach, and San Diego. These four airports are set apart by having the strictest noise rules in the United States, all of them adopted prior to the national Airport Noise and Capacity Act (ANCA) of 1990. No other U.S. airports have curfews or noise limits or noise budgets.

The four airports' strict rules date back to 1971, when California adopted airport noise regulations establishing a requirement to publish noise contours and determine if an airport has a "noise problem." While the preamble stated 60 CNEL (Community Noise Equivalent Level) was the desired threshold, economic considerations resulted in a threshold of 65 CNEL, which is approximately 65 DNL (day night noise level) and identical to the European LDEN (day evening night level).

Noise sensitive airports were required to adopt a plan to achieve compliance. Most airports used corrective sound insulation programs; an insulated residence was no longer considered to be impacted. This presentation, however, focuses on those airports that instead used noise restrictions and curfews to address unacceptable noise levels.

For San Diego's part, the airport has a night departure curfew that has been in place since 1976. The other three airports, to be covered in more detail, have various protections in place:

- *Long Beach Airport.* Rules, adopted in 1985, include single event noise limits at noise monitors, night restrictions, and a noise budget. Airline and cargo flights are limited to 41 per day, with increases allowed if the noise level at the nearest home is below 65 CNEL. Currently, 51 flight are permitted per day, calculated on an equal-energy basis of the noise budget.
- *John Wayne Airport.* Rules, adopted in 1985, define single-event noise limits at departure noise monitors, night restrictions including a prohibition on nighttime air carrier operations, and limits on numbers of flights and passengers.
- *Santa Monica Airport.* Rules, adopted in 1984, put in place a nighttime departure curfew, single-event limits, and limits on the number of aircraft based at the airport.
- *Note:* The decision to impose curfews on night departures and not arrivals is based on an interpretation of the Interstate Commerce Clause, with departure limitations considered less likely to interfere with interstate commerce than the same types of restrictions on arrivals, at least by the dominant legal theory in the year the rules were put in place.

The four airports discussed in this presentation are the only four in the country with mandatory nighttime flight restrictions, with 2,996 others having voluntary versions in place. And no airport has adopted a new nighttime restriction after enactment in 1990 of the Airport Noise and Capacity Act.

ANCA was intended to balance aviation interests with community interests, but was instead highly favorable to the aviation industry. Implementing regulations that did restrict aviation, Federal Aviation Regulation (FAR) Parts 91 and 161, are summarized in Figure 6.1-1. Elaboration on Part 91 restrictions is provided in Figure 6.1-2.

Relevant highlights of the Long Beach, John Wayne, and Santa Monica airports and their major regulations are as follows.

LONG BEACH

The airport, located about 20 miles south of Los Angeles, has five runways, including a very long one, with many residences located off the end of each major runway. The homes in the area were effectively company housing when Douglas and Boeing had company bases there, but this association was lost when the companies left the area, and opposition to noise has soared.

A 1985 settlement agreement resulted from litigation over a 1983 ordinance, under which cargo and airline operations were limited to 15 per day. The settlement agreement expanded airlines to 41 departures per day; imposed single-event noise limits at airport monitors; and prohibited nighttime airline and cargo operations. The noise budget was based on CNEL, and the tradeoff in terms of the noise budget was on an equal-energy basis. That is, decreasing the CNEL by 3 dB would allow a doubling of departures.

Airlines argued against the restrictions, threatening to cease their operations there. Despite this stance, in the year 2000, Long Beach Airport served about 650,000 passengers, contrasted with 50,000 passengers annually in 1985, and in the pre-Covid year 2019, the airport served 3.5 million passengers—a five-fold increase since 2000 despite the restrictions.

Today, because of decreased airline fleet noise levels, the noise budget permits 51 operations per day. And the community exercised its decision-making power to approve a major airport expansion.

JOHN WAYNE

This small airport—located just north of the very wealthy community of Newport Beach, with its many extremely expensive homes—is the most noise-restricted airport in the United States. Its rules, adopted as part of a 1985 settlement after years of litigation, was probably the impetus to industry to introduce ANCA. The complex rules contained a wide variety of limits on airport development and operations to ensure limitations on airport growth even if challenged under the Interstate Commerce Clause or other federal legislation.

Airport rules limited annual passengers to 8 million per year and its new terminal to seven gates, with additional limits on square footage and on design factors to ensure the terminal remained small. Noise limits are in place based on seven noise monitors, and airline departures are limited. The fleet is divided into Class A, allowing 41 departures per day at the least restrictive noise limit; Class AA, permitting 34 departures per day at a stricter noise limit; and Class E, allowed unlimited departures at the strictest noise limit as long as the 8 million-passenger limit is not exceeded.

Noise limits were based on the 1985 fleet, which was separated by class leaving only certain aircraft qualified to fly (see Figure 6.1-3). Class E was created to thwart an airline complaint that its aircraft, which were much quieter, should be allowed many more flights. The limits for Class E were developed not based on sophisticated noise level analysis, but instead by a community committee standing by the noise monitors and voting that the BAE 146 was the aircraft that made their cut for the unlimited operations category.

As the fleet became quieter, airlines were able to block seats and reduce weight to qualify a Class A aircraft as a Class AA. Over years of measuring, it has been determined that the relationship of departure noise to aircraft weight was about 2 dB per 10,000 pounds. So, as airlines blocked seats to qualify for Class AA designation, more flights occurred for the same number of passengers, achieving only a meager noise reduction.

The community exercised its decision-making influence toward eliminating the Class AA distinction and allocating the flights to Class A, resulting in fully loaded aircraft without blocked seats. And, as the fleet grew quieter, the community allowed terminal growth from seven gates to 21, with an increased passenger limit of 15 million annually.

In part, the community supported growth because of the airport's convenience for them. And, as the 1985 agreement was reaching its expiration, a new agreement would include the FAA as a signatory party to ensure the access plan could not be challenged as an ANCA violation.

Even with the community playing a key role in approval of airport rules, the airlines—which said in 1985 the rules were too strict and they would move their operations—have flourished, with some saying John Wayne is their most profitable airport.

SANTA MONICA

This general aviation airport in West Los Angeles has a long history of noise problems and also litigation, which started in 1967 over business jet operations and led ultimately to the current airport rules that were adopted under a settlement agreement in 1984. The agreement created a nighttime departure curfew, single-event noise limits at the airport's noise monitors, and limits on the number of based aircraft, while allotting some airport land for non-aviation uses.

Under a 2017 consent decree, the city—which had wanted to close the airport—agreed with the FAA to keep the airport open until the end of 2028, and has shortened the runway under the same agreement to meet FAA runway safety area requirements.

From the experience of the above three California airports, it has become clear that communities can play a crucial role in noise-related decision-making. Notably, only 30 percent of annoyance response to noise is based on acoustic factors, with other, non-acoustic factors playing a huge part in people's judgments. Much less is known about non-acoustic factors than acoustic ones, but some studies have shed light on non-acoustic influences.

Some important non-acoustic factors are listed in Figure 6.1-4. These include fear associated with the noise, whether the noise is avoidable, consideration of non-noise problems such as air quality, general sensitivity, and whether the noise is associated with a worthwhile benefit.

Going forward, policy decisions must consider which factors should be under federal versus local management. ANCA's restrictions are leaving communities with the sense that they have no control over decisions, whereas community input on decisions is in fact key to tailoring decisions to each airport's unique circumstances. And communities are keeping an eye to the future—with many municipalities having already adopted rules prohibiting the operation of unmanned aerial vehicles, for example.

ANCA Implementing Regulations

- Balancing was accomplished in two Federal Air Regulations
  - FAR Part 91
    - Required phaseout of Stage 2 aircraft by December 31, 1999
      - (only applies to aircraft > 75,000 pounds)
  - FAR Part 161
    - Restricts airport ability to regulate airport access based on noise
      - (Restrictions apply to all aircraft)
    - No airport has ever had a Part 161 application approved

Figure 6.1-1 *Federal Aviation Regulations FAR Parts 91, 161*

Limits Established by FAR Part 161

- No airport noise or access restriction on the operation of a Stage 3 aircraft, including but not limited to –
  - (1) a restriction as to noise levels generated on either a single event or cumulative basis;
  - (2) a limit, direct or indirect, on the total number of Stage 3 aircraft operations;
  - (3) a noise budget or noise allocation program which would include Stage 3 aircraft;
  - (4) a restriction imposing limits on hours of operations; and
  - (5) any other limit on Stage 3 aircraft; shall be effective unless it has been agreed to by the airport proprietor and all aircraft operators or has been submitted to and approved by the Secretary pursuant to an airport or aircraft operator's request for approval in accordance with the program established pursuant to this section."

Figure 6.1-2 *Elaboration on FAR Part 161*

John Wayne Airport (cont'd)

- Noise limits based on 1985 fleet
  - Class A: Allowed B737-200 and DC-9 but not the B727
  - Class AA: Allowed B737-300
  - Class E: Only allowed the BAE 146
    - Class E created to thwart an airline complaint that their aircraft were much quieter and should be allowed many more flights
    - Community committee stood by the noise monitors and identified BAE 146 as the aircraft that was ok for this category.

Figure 6.1-3 *John Wayne Airport noise limits established which aircraft would be allowed to fly*

Some Non-acoustic Factors

- Fields, (1993)
  - Fear
  - Could noise be prevented?
  - Awareness of non-noise problems?
  - General sensitivity
  - Is noise source important?
- Bartels et al, (2022), background noise, access to open space and quiet side of dwelling, time of day – respite, insulation, operational intervention, attitudes, trust in authorities, coping strategies
- Gsejtland, (2017) Low vs high rate of change of noise over time

Figure 6.1-4 *Non-acoustic factors that influence annoyance*

6.2 Noise Situation at the Berlin Airport: Single-Event Noise Fee and Noise Protection Program

Ralf Wagner—Berlin Brandenburg Airport

A new, single-event noise fee system was put in place recently at Germany's Berlin Brandenburg Airport, replacing a more generalized fee system based on average maximum noise levels for each aircraft type. Another important aspect of the airport's noise management efforts is a noise protection program that covers the costs for improvements deemed necessary to control indoor, as well as outdoor, noise levels at homes near the airport.

From his perspective as a noise protection expert with Germany's Berlin Brandenburg Airport, Ralf Wagner discussed the airport's noise charge model and noise protection program, after providing context by sharing basic facts about the airport.

The Berlin Brandenburg Airport, located just south of the German capital in a suburban area, as shown in Figure 6.2-1, serves a geographic area of some 10 million people. Annual passenger enplanements are third among airports in Germany, behind only the Frankfurt and Munich airports.

Until recently, Berlin Brandenburg's approach to aircraft noise fees, like the model being used at most German airports, was based on aircraft type. Each aircraft operating at the airport was subject to a charge for takeoff and landing, based on the aircraft type's average maximum level measured with the airport's noise measurement system.

Information about this previous approach, including aircraft categories and associated noise levels and charges, is provided in Figure 6.2-2. This previous model has certain advantages, including its simplicity, but also has downsides in terms of effects on flight procedures.

Under this prior noise charging model, expected flight procedure effects were not always seen. For example, Air Berlin's departure procedure was changed in 2011, with its cutback altitude during takeoff lowered from 1500 to 1,000 feet. An adaptation was therefore required for the particular aircraft being operated, but fairness required that the change be made for the same type of aircraft across airlines. Likewise, an adaptation was required when Lufthansa changed its departure procedures in 2014.

The chronology of the two airlines' changes in flight procedures and, in turn, noise categories is shown in Figure 6.2-3. Under Germany's laws, application to the authorities for changes to standard charge tables required prior consultation with all of the airport's airlines and sharing of all related data that had been gathered.

Disadvantages of the charge model based on aircraft type included a substantial time lag in achieving noise-related operational changes, as well as a lack of short-term benefits for airlines using noise-optimized flight procedures, given that noise reduction was only factored into average noise levels for the particular type of aircraft. "The good ones are therefore not rewarded, and the more noisy ones are not held accountable."

Examining noise abatement departure procedures (NADPs), NADP-1, with a steeper climb around noise-sensitive areas near the airport, resulted in less noise in highly affected areas, but in slightly more noise in areas laterally more distant from centerlines, than from NADP-2, which are abatement procedures for further out. Using NADP-1, an aircraft gains altitude quite quickly, but at its high altitude, spreads noise further. Consideration needed to be given to which procedure was more advantageous based on the locations of populated areas around the airport. Also, conditions determining individual aircraft noise events such as weather, actual takeoff weight, and aircraft/engine combinations were not taken into account under the previous model.

Given the pros and cons of the system being used, the airport concluded that a single-event-based fee system should be introduced in place of the old method. The system, which was implemented in September 2022, is cost-based, as required under German law, and not designed to produce income for the airport.

Challenges with the new model included how to address noise events outside certain noise or operational boundaries, such as when thunderstorms and high winds required a change in standard departure and arrival procedures. In this type of situation, the fee would revert to the aircraft-type based noise category system. Certain technical modifications required adaptation for the new system. For instance, an interface had to be created between the noise monitoring system and the fee collection done by a different, accounting-focused department.

The airport introduced a semiautomatic verification of noise events to avoid charging airlines incorrectly—if a dog barks close to a monitor microphone, for example—and new reference monitors were put in place. More than 30 monitors with calibrated microphones are being used, with at least three monitors located along each standard arrival and departure route. Sophisticated processing units are used along with a system for remote data transfer to the airport's server that processes the data.

Refinements for the new fee model are summarized in Figure 6.2-4, which also shows differences between the previous and current approaches. In the new system, three reference noise measuring points are used to measure maximum noise level, and the three levels are averaged.

A new standard table identifies current charges, based on 11 noise categories instead of the previous seven. The minimum and maximum charges are relatively unchanged, and additional surcharges are still in place for certain circumstances. Nighttime flights incur a surcharge, for example (although night flights are very rare under a nighttime curfew in place).

New noise categories are presented in Figure 6.2-5, with associated fees ranging from €40 for each movement below 63 dB(A) to €7,500 per movement above 81 dB(A). About 70 percent of aircraft are currently charged under the system and, as the figure shows, most current noise events fall under categories 4, 5, and 6. Notably, however, the model was only put in place on Sept. 1, 2022, and a shift is expected going forward, from louder to less noisy categories.

Moving to a discussion of the noise protection program, planning approval for the program was obtained from the proper authorities in 2004, with a supplemental approval for nighttime flights and nighttime protections in 2009. Over the years—and based on court actions that were brought during the time period—the protection goals and zones have become clear.

The size of the protection zone is 155 square kilometers, or about 60 square miles, within which nearly 27,000 housing units and some 50 public institutions are located. This huge zone, depicted in Figure 6.2-6 with relevant noise contours, has called for a financial investment in noise protection that is among the largest in the world. The figure's blue line reflects a nighttime contour with an average Leq of 50 dB(A), or a number above threshold (NAT) of 6 times 70 dB(A) outside, and this applies to the protection of rooms such as nurseries and bedrooms that are used at night. For rooms used during the day, protection is associated with an Leq of 60 dB(A). The planning approval also addresses compensation for outside premises such as terraces, gardens, and balconies, requiring the airport to pay at least €4,000, or 2 percent of a house's market value, when the house is within the contour shown in green. Within the very small innermost contour, shown in orange and defined by a 70 dB(A) Leq, house owners can opt to sell their property to the airport.

Nighttime legal requirements within the protection zone are similar to those under Germany's federal law, designed to ensure "undisturbed sleep." The protection target within rooms is 6 times 55 dB(A) per average night, which can be achieved by using common noise protection measures.

Daytime protections must ensure "undisturbed communication," resulting in an NAT of 0.005 times 55 dB(A) per day. "This comes from a court decision that said we have to ensure that 55 decibels is not being exceeded within the loudest six months of the projected year. This is a very high target, requiring us to apply the best available technology to attempt to achieve it."

The procedure for owners to obtain protections under this program is summarized in Figure 6.2-7. First, a homeowner submits an application, after which a thorough engineering company examination is undertaken and a calculation is made of the cost of necessary measures.

Property market value expertise (PMVE) is required above a certain threshold of cost, which has been derived from statistical data. When this is not required, the documents are sent to the owner with a guarantee the airport will cover the costs of the measures laid out by the engineering company. When the PMVE is required, the airport takes this same action of covering the costs, unless the costs are greater than 30 percent of the PMVE, in which case the owner receives money directly in the calculated amount. This 30 percent threshold is met in about two-thirds of cases in the daytime protection zone.

While noise protection in Germany would typically be thought of as simply installing soundproof windows in place of ordinary windows, the strict daytime NAT target also requires insulation of walls, roofs, and ceilings. These changes are very unpopular among owners, and are therefore very rare. In rooms used at night, the measures must ensure proper ventilation to essentially substitute for the possibility of leaving windows slightly open at night. The ventilators used for this purpose are expensive, currently costing about €2,000, and homeowners are able to recuperate the costs from the airport

As of Sept. 30, 2022, more than 22,000 applications had been submitted to the noise protection program, whose status is summarized in Figure 6.2-8. Of the 22,000, about 13,000 have received an offer for installing protective soundproofing measures. Many who have received the offers to cover the costs of anti-noise measures have so far refused to commission building companies to do the work, the cost of which far exceeds €20,000 on average. When homeowners are entitled to direct financial compensation, however, they tend to submit their claims without delay.

As a concluding point, the total budget for the Berlin Brandenburg Airport's noise protection program is nearly €750 million. Commitments reached €560 million by the end of June 2022, and recent figures indicated expenditures had reached €435 million.

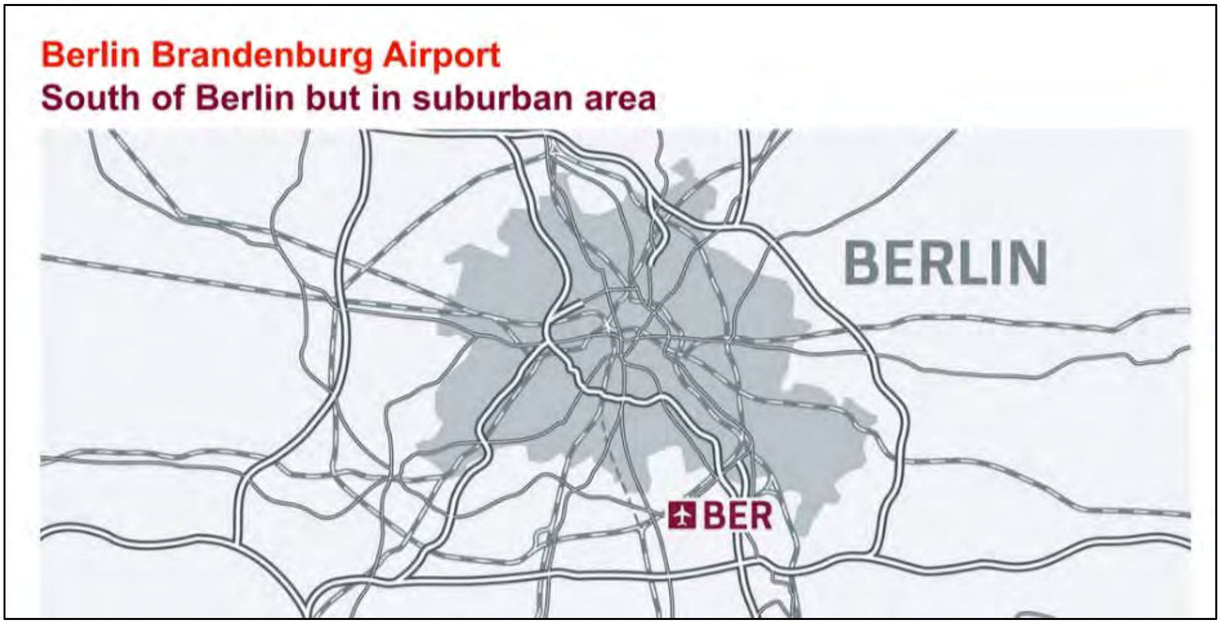


Figure 6.2-1 Berlin Brandenburg Airport is located in a suburban area just south of Berlin

Actively Reducing Noise

Airport Noise Charge - A/C type based (previous model)

Category	Noise Level	Charge	Aircraft Type (examples)
1	up to 70,9 dB(A)	50 €	B350, C25B, C510, CL60, E135, F2TH, GLF5, GLF6, LJ35, helicopters
2	from 71 dB(A)	62 €	AT43, B462, BE20, C25A, CRJ1, DH8C, E55P, GALX, PAY1, PC12
3	from 74 dB(A)	80 €	A318, A319, B736, B737, E170, E190, F100, F70, A320-Sharklets
4	from 77 dB(A)	125 €	A310, A320, A321-200, B733, B734, B735, B752, B753, C160, SU95
5	from 80 dB(A)	515 €	A332, A333, A343, B744, B763, B764, B772, MD82
6	from 85 dB(A)	3.000 €	AN12
7	from 90 dB(A)	7.500 €	A124, Non-Annex Chapter 2

Figure 6.2-2 Berlin Brandenburg Airport's previous noise charge model was based on aircraft type

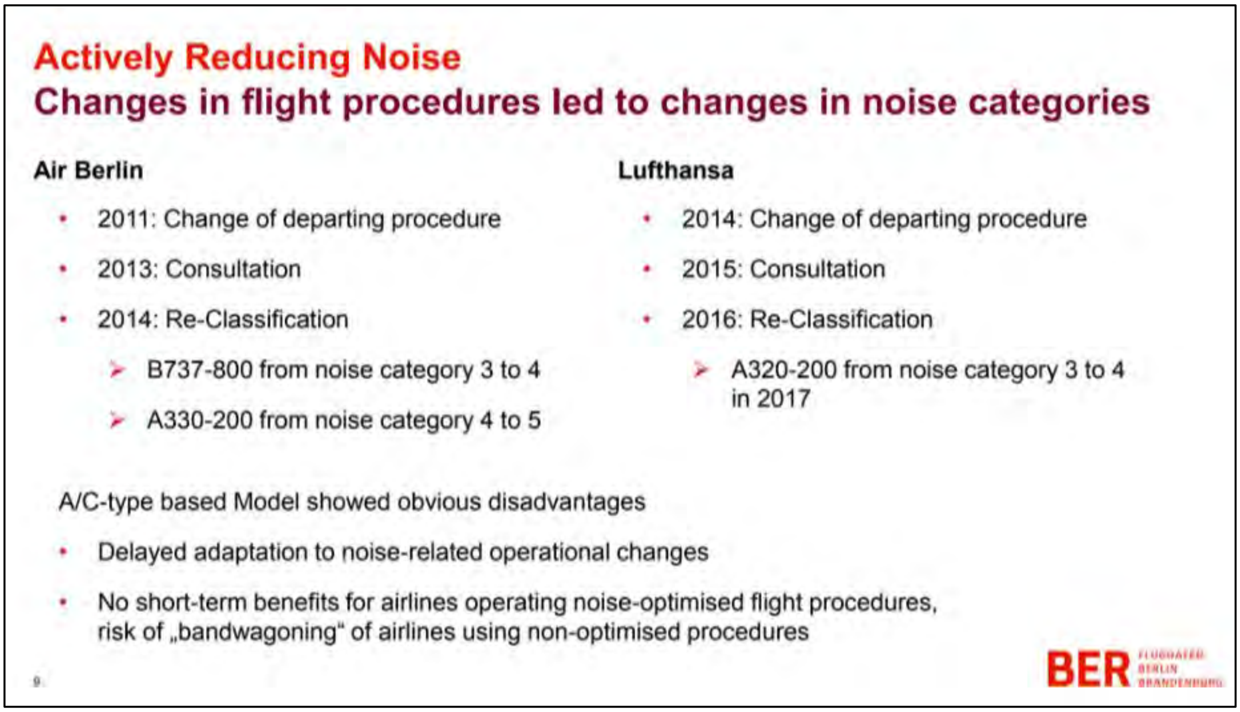


Figure 6.2-3 Air Berlin and Lufthansa: Changes in flight procedures, noise categories

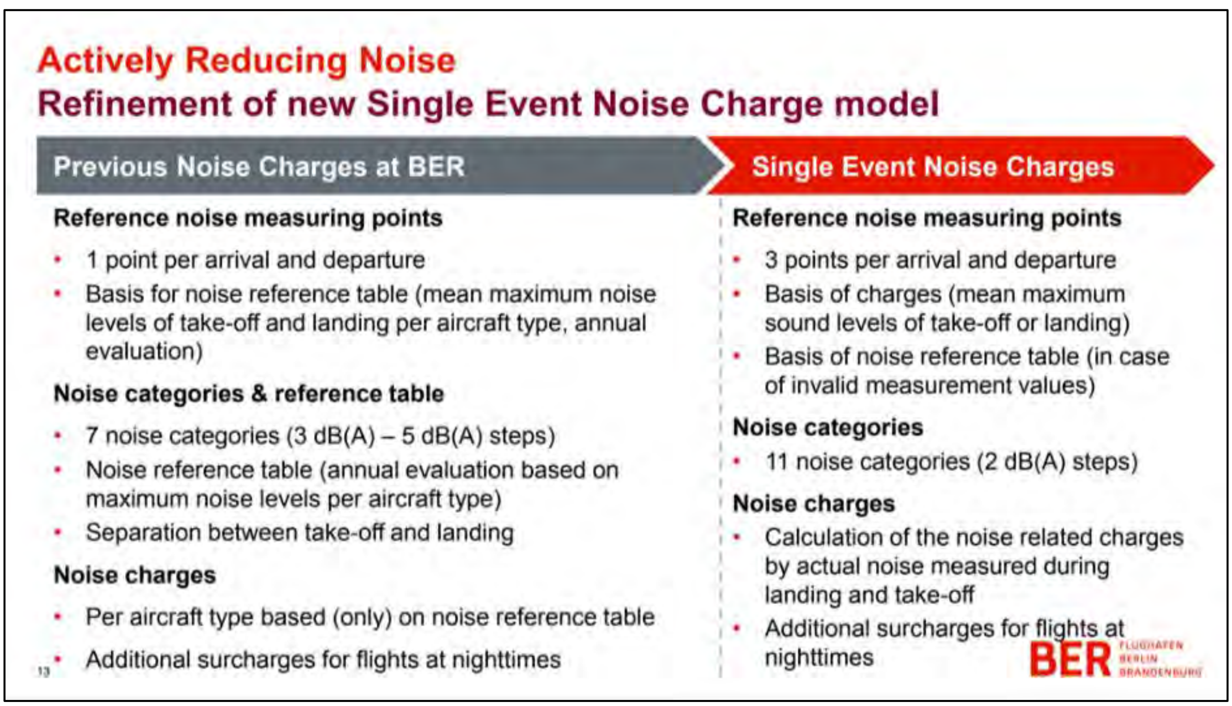


Figure 6.2-4 Comparison of previous and current noise charge models

Actively Reducing Noise
New Noise Categories and their expected Shares in movements

Category	Noise Level	Fee	**Expected shares** (movements per noise category*)
1	up to 62,9 dB(A)	40 €	5,0%
2	from 63 dB(A)	50 €	4,4%
3	from 65 dB(A)	62 €	10,6%
4	from 67 dB(A)	80 €	26,4%
5	from 69 dB(A)	105 €	37,0%
6	from 71 dB(A)	220 €	14,4%
7	from 73 dB(A)	300 €	1,9%
8	from 75 dB(A)	515 €	0,3%
9	from 77 dB(A)	1.500 €	0,1%
10	from 79 dB(A)	3.000 €	0,0%
11	from 81 dB(A)	7.500 €	0,0%

* Traffic forecast for BER, Aircraft fleet of 2019

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Figure 6.2-5 New noise categories and fees, along with expected percentage of movements

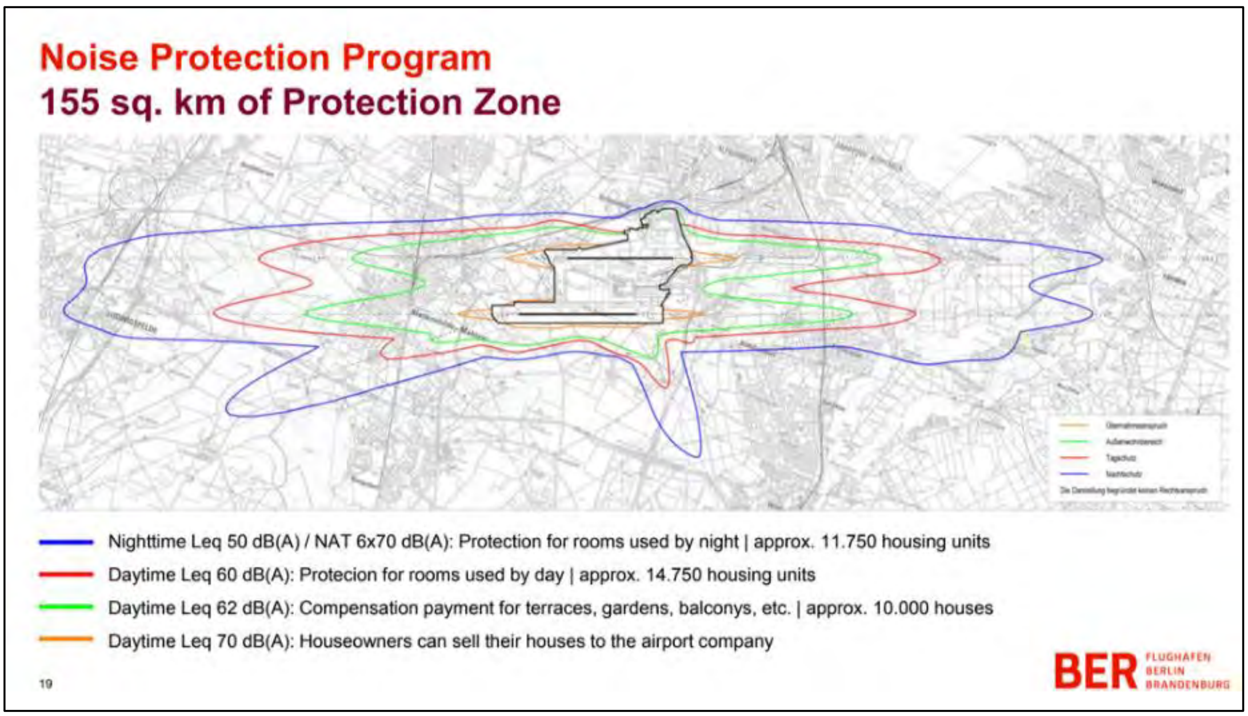


Figure 6.2-6 Noise protection zone contours: Nighttime and daytime

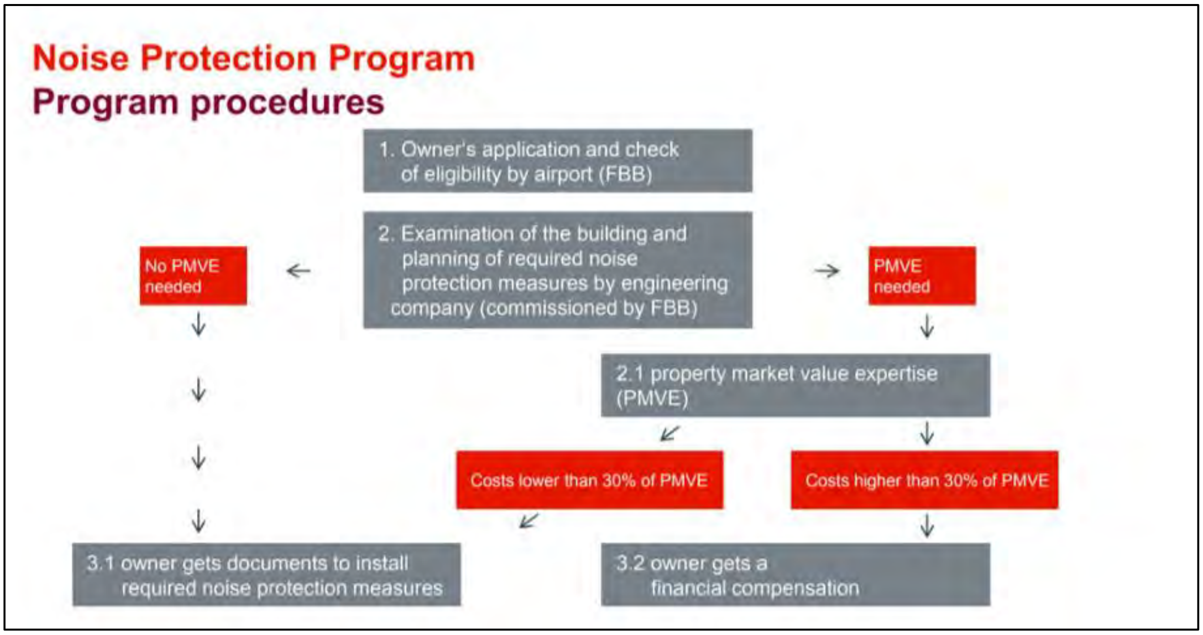


Figure 6.2-7 *Procedures for homeowners to seek protection measures or associated compensation*

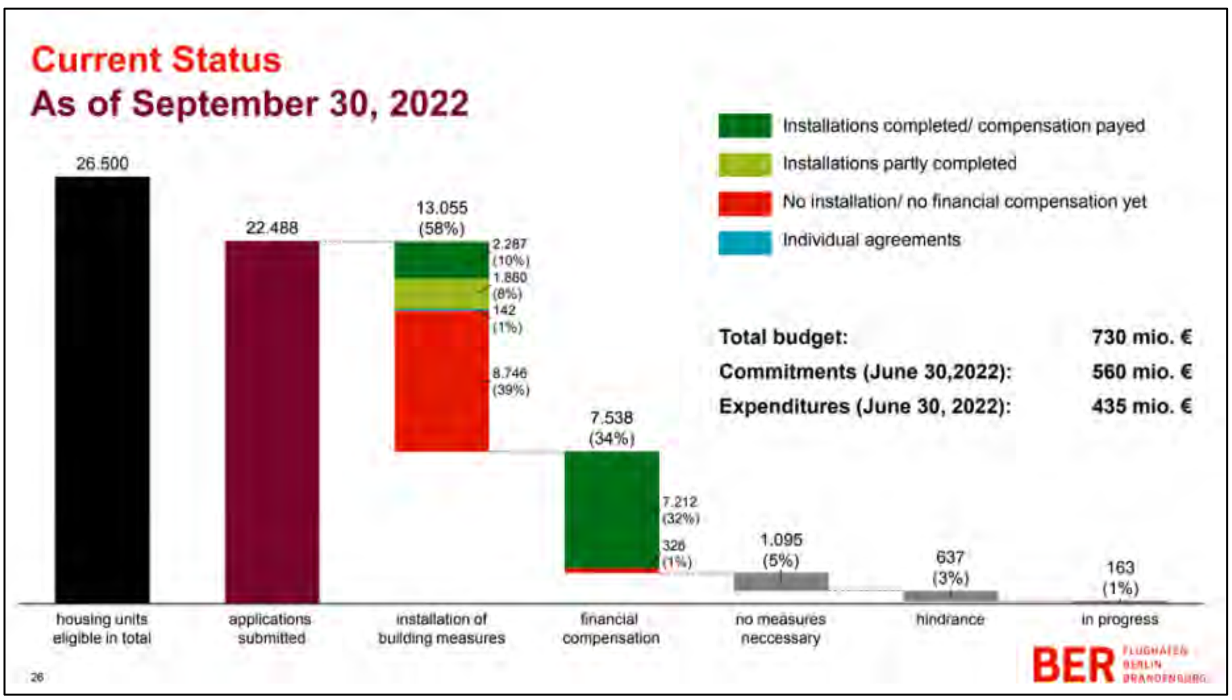


Figure 6.2-8 *Noise protection program status*

6.3 Managing Noise Annoyance Around the Madrid-Barajas Airport

Ana García Sainz-Pardo, Eva Santos González, and Antonio Donoso López —SENASA

The busy Madrid-Barajas Airport ensures that the wide range of perspectives is considered throughout the process of noise control decision-making. Along with flight procedures and paths optimized to the extent possible and measures such as awareness campaigns for pilots, air traffic controllers, and others, the open dialogue can help point the way to the most effective solutions for reducing noise and community annoyance.

Ana García Sainz-Pardo, along with Eva Santos González and Antonio Donoso López, spoke about reducing noise annoyance around Spain's Madrid-Barajas Airport (Madrid Airport). As experts on the Aviation Noise Team at the state-owned company SENASA, the three provide technical support related to noise and associated annoyance around all of Spain's airports.

The Madrid Airport underwent major expansions in 1998 and 2006 (see Figure 6.3-1), and today operates as a four-runway system with segregated simultaneous parallel operations. The airport ranked 5th in 2019 among European airports in terms of number of passengers, and 11th for international passengers.

An environmental follow-up commission was created for the airport as a result of its two expansions, to make decisions with input from all stakeholders. Community engagement, including the steps presented in Figure 6.3-2, is key as the commission strives for optimal solutions to noise and other issues while building trust between the airport and nearby residents.

In the commission's work, various forums bring stakeholders together to ensure diverse perspectives are represented. Technicians representing the groups of stakeholders must understand noise problems, including associated tools, radar systems, noise monitoring systems, and even flight data recorders that could shed light on problems and help point the way to effective solutions.

In an example of the efforts the commission has overseen, when specific nighttime flights were identified as creating annoyance, a reschedule or an exchange of an aircraft for a less noisy one was achieved in some cases. Delaying a 6 a.m. departure by even an hour can alleviate people's annoyance.

The most crucial problem after the two airport expansions was dispersion from the tracks. Most aircraft did not follow the new runways' lines, and noise and annoyance were increasing in unexpected places. A campaign was therefore undertaken in 2006, following a global forum, to inform pilots and their airlines about the tracks their aircraft had followed compared to the nominal paths, and information was also provided about the consequences of these actions. And pilots were also informed about how other pilots with similar aircraft had succeeded in following the tracks.

While the situation improved significantly after implementation of this education campaign, the problem lingered to an extent. In response, a coordinated effort among aeronautical authorities and operators led to a regulatory system of sanctions. When flights failed to follow the appropriate flight path within a regulatory tolerance or did not comply with rules for reducing noise, the airport notified the proper authority, and an administrative file and investigation was initiated. If an investigation found no justification based on factors such as weather, safety, or traffic congestion, the company was fined. As a result of this system—in which SENASA provided extensive

SENASA

technical and legal support—a significant improvement has been achieved in sticking to defined routes and reducing flights over populated areas. Improvements in numbers of dispersions is illustrated in Figure 6.3-3.

In parallel with the 2006 noise awareness campaign for pilots and their companies, training related to noise and CO_2 emissions became a requirement for air traffic controllers. It was SENASA, which was at that time in charge of this type of air traffic controller training, that implemented the courses.

Reduction of annoyance should begin with the optimization of flight paths through less populated corridors. In one important action that substantially reduced annoyance experienced by people around the Madrid Airport, the airport adjusted the runways used for nighttime flights based on a study comparing various indicators of noise and annoyance.

Compatible land use is another critical approach to reducing airport noise and annoyance levels. In reports created since 1998 by Spain's aviation authorities, new residential areas are prohibited under the noise contours 50 dB(A) Ln (night) and 60 dB(A) Ld (day), and new building permits are not allowed in certain affected areas. In another major effort, Spain has undertaken noise insulation programs to minimize annoyance of people inside their homes located within defined noise contours. More than 13,000 homes have been acoustically insulated under this program. These efforts are summarized in Figure 6.3-4.

To measure noise levels around the airport in support of noise management efforts, permanent noise monitors are located in areas surrounding the airport. Specifically, 27 monitoring terminals, and additional portable measurement points, provide reliable, up-to-date acoustics information. The system supports checks of compliance with noise regulations and correlates noise events with operations. The noise monitoring system received accreditation under the ISO 20906:2009 standard, becoming the first in the world to receive this certification.

When overflight of an area cannot be avoided, measures to minimize noise and annoyance include: gaining more altitude, using an approach threshold displacement, changing the flight path angle, or using new technologies such as those associated with performance-based navigation (PBN). The Madrid Airport established a minimum flight level at points over populated areas for aircraft that could reach this minimum altitude. The noise mitigation measures are controversial among some who question the balance in the measures between noise and CO_2 emissions.

To encourage quieter fleets, the Madrid Airport implemented two major measures:

- *Increased landing charges for the noisiest aircraft.* Along with several other Spanish airports, the Madrid Airport adjusts charges based on how far an aircraft is from Chapter 3 certification: If an aircraft is certified under Chapter 4 or Chapter 14 of ICAO Annex 16, the charge is less.
- *Noise quotas.* Each airline consumes points based on the noise from its fleet operations over the previous year, using more points the noisier the aircraft is. The airline must stay within its points quota by using its quietest aircraft to compensate when its points run too low as the year progresses. The measure is considered an operations restriction, as it may ultimately restrict access for certain aircraft.

Other restrictions have also been implemented, according to an airport's size, the sources of noise, and the placement of the closest homes. Examples include "Prohibition of training and test flights to avoid the additional annoyance to the nearest communities" and limits on the use of auxiliary power units (APUs), engine tests, and reverse thrust at night. Operational restrictions are the option of last resort under the "ICAO Balanced Approach."

Following the presentation, a participant asked about the role of emissions and fuel burn in Spanish aviation authorities' consideration of environmental policies, and whether aircraft operators are resistant based on cost considerations. The response: It is only in recent years that much attention has been paid by aviation stakeholders in Spain to the problem of CO_2 emissions and climate change. Studies have slowly been introduced into the decision-making process, but given stakeholders' opposing viewpoints, additional research is needed to support decision-making in this area.

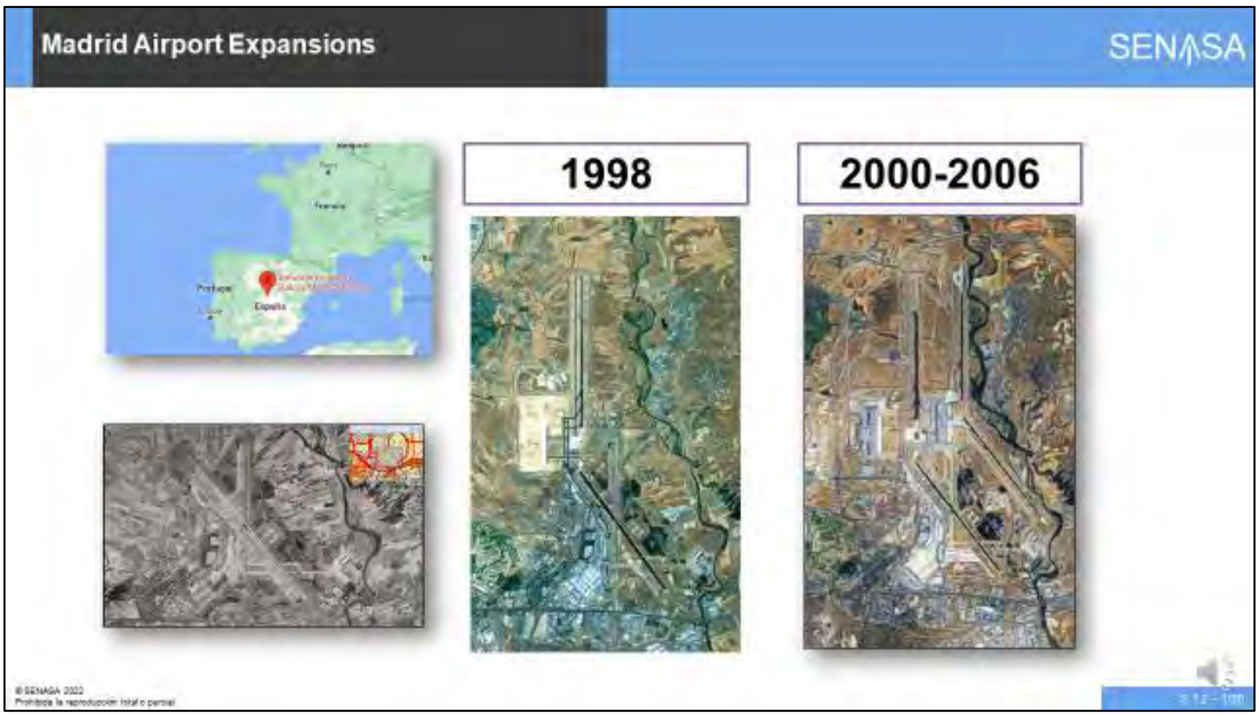


Figure 6.3-1 *Two major Madrid Airport expansions resulted in the current airport configuration*

Figure 6.3-2 Efforts for extensive communication among stakeholders

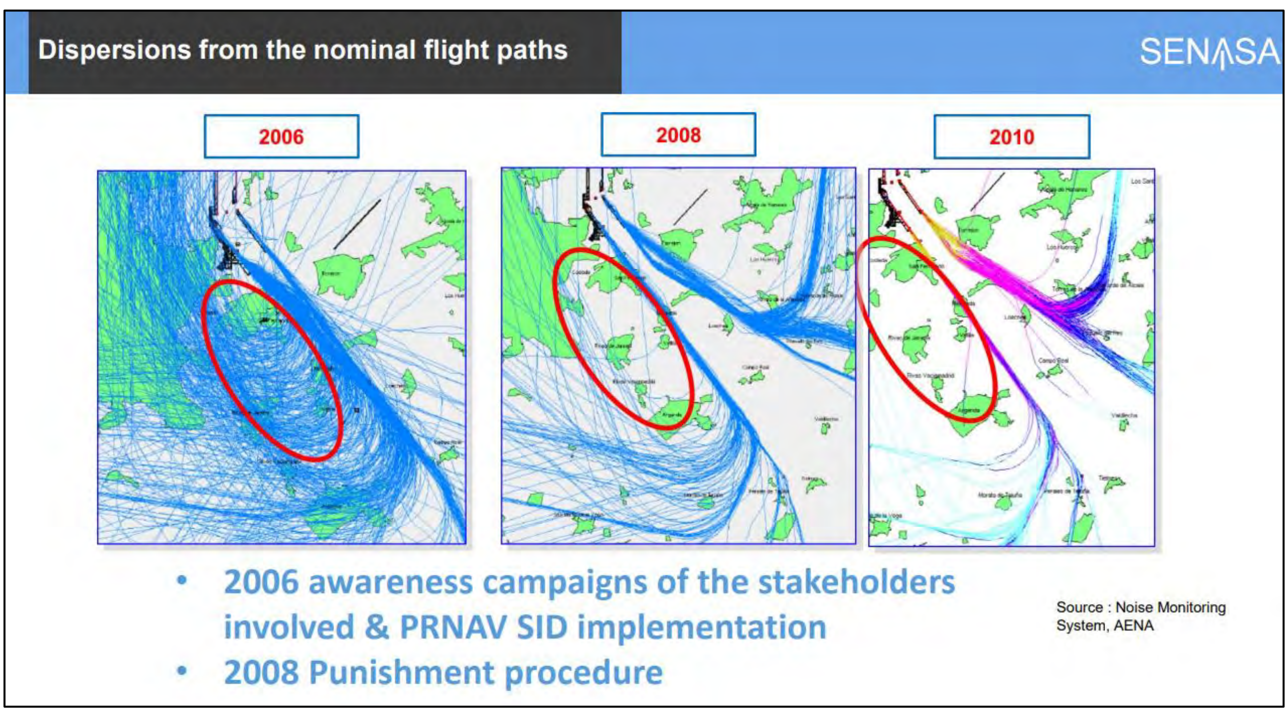


Figure 6.3-3 Dispersions from the nominal flight paths

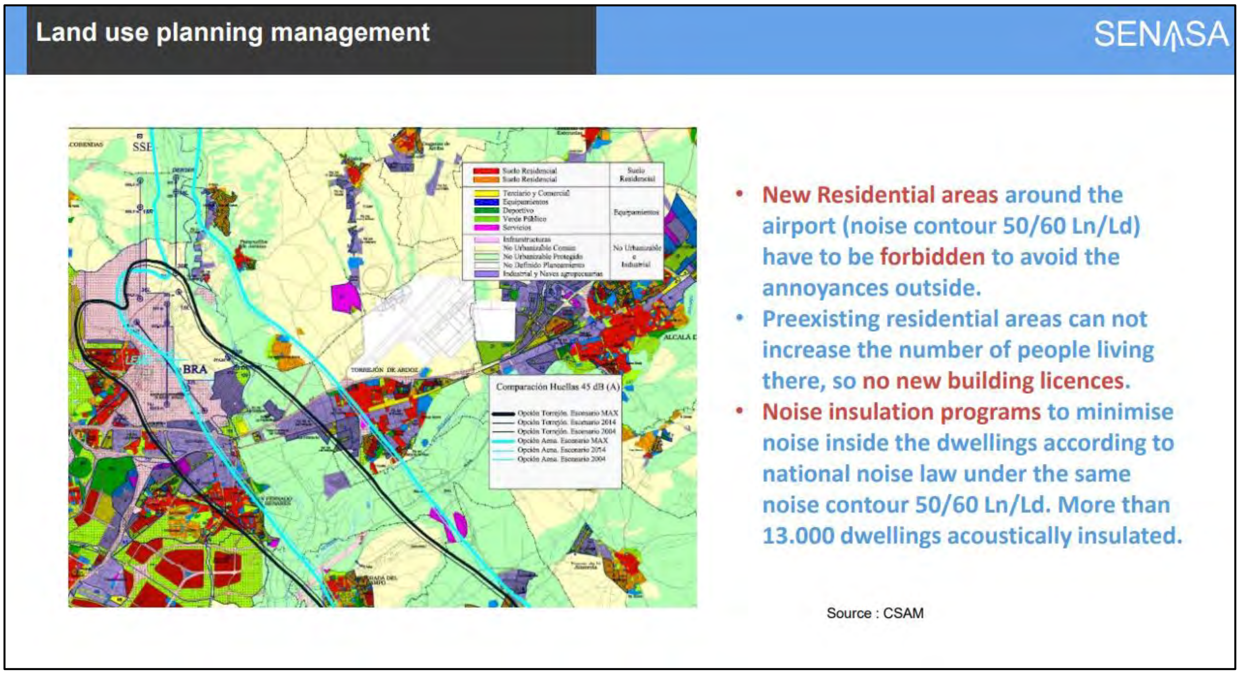


Figure 6.3-4 *Land use planning management*

6.4 Noise Situation at Dallas Fort Worth International Airport

Sandra Lancaster—Dallas Fort Worth Airport

The Dallas Fort Worth Airport vigorously monitors, and takes steps to curtail, noise around its facility. As a central element of its noise control strategy, the airport actively engages with nearby communities to keep them informed of noise-related challenges and involved in mitigation steps.

Presenter Sandy Lancaster serves as Dallas Fort Worth Airport's (DFW) assistant vice president for environmental development programs, a position that places the noise compatibility program within her purview.

DFW airport, one of the last greenfield airports built, includes seven runways and five terminals within its 17,000-plus acres of land. The airport is the second-busiest in the world in terms of passenger counts (and these numbers have returned to near-pre-pandemic levels). Basic statistics related to the airport are provided in Figure 6.4-1.

The airport's aspirational goals—referred to as its "North Stars"—include six categories of objectives: climate action, energy performance, circular economy, biodiversity, equity, and health and wellness. In each area, specific "aggressive" metrics are targeted; for example, the airport's goal is to hit net zero carbon by 2030, 20 years ahead of the aviation industry target.

Before the airport was built in the area, Dallas Fort Worth was generally undeveloped, with a few cities on the periphery. Figure 6.4-2 shows noise exposure as predicted for 1985 during the planning phase on the left, and the airport as it exists today on the right. The plan was to have 10 runways, 13 terminals, and four large cargo areas, which did not fully come to fruition.

The land on which the airport was built was farmland in the late 1960s and early 1970s while the airport was being planned, DFW plans included potential future noise scenarios. Aircraft were very loud during that period, and also the assumption was aircraft would fly straight out from the runway trajectory.

Zones were created using noise contours of 60 DNL (Zone A), 65 DNL (Zone B), and 70 DNL (Zone C), and nearby cities were to develop areas compatible with the predicted amount of noise. As a result, most airport noise today is over areas that achieved compatible land use, including off the ends of the runways, and surrounding residential areas are by-and-large situated outside of the noisiest contours.

DFW Airport's noise program has evolved from a reactive posture to a very proactive one. After a contentious period during the airport's growth, including many lawsuits related to noise and other community concerns, the airport built on lessons learned to create methods of engaging with the community and took steps to address concerns. For example, the airport established a noise and flight monitoring system, a community forum, and a noise strategic plan that looked at airport issues locally, regionally, and even nationally to understand and potentially broadly influence aviation-related issues. The airport has developed good relationships with communities around the airport, striving for transparency and letting communities know, for example, of any relevant changes expected in operations.

In some cases, mitigation steps have been completed in areas with unacceptable noise levels. Figure 6.4-3 highlights the Irving, Texas example of a completed mitigation area (with noise contours from a 1992 environmental impact statement). Specific mitigation steps are the subject of Figure 6.4-4. The purple shading highlights the area of mandatory mitigation where another runway had to be built. The orange rectangle marks an optional purchase zone where houses were generally positioned within the 70 DNL area. Within the green area, an easement program was undertaken that did not change the land use, but rather provided funding to people to insulate their homes. The grayish color is an area of soundproofing as a completed mitigation step targeting apartments, schools, and churches. At the time this policy was put in place, in the mid-1990s, this was the most aggressive mitigation program in the country.

DFW Airport's strategic plan consists of four basic pillars: promotion of compatible land use, listening to noise via monitors, monitoring flight tracks, and engaging with communities. In promoting compatible land use, Figure 6.4-5 overviews the various noise contours, with red representing the forecast of 1985 operations that resulted in the land use ordinance, and green delineating the airport's 1992 environmental impact statement contours. Within these contours, cities have tried to develop compatibly. The upper right graphic shows the area off the west diagonal runway where a land use ordinance was set up as a result of a legal settlement. As land runs out, issues of encroachment have arisen as houses are built right outside the airport's property boundary.

The airport has placed about 35 devices around the airport that monitor community noise as well as aircraft noise, and data collected is matched with flight track data to better identify noise sources. Cumulatively, if actual noise is greater than predicted noise from a policy contour, the airport must either restrict aircraft operations or mitigate additional properties. Quieter aircraft with modern technologies have helped greatly in ensuring that predicted noise levels are not exceeded.

With aircraft taking off and landing into the wind, DFW Airport flights use "south flow" flight tracks about 70 percent of the time, landing from north to south and departing to the south, and "north flow" flight tracks about 30 percent of the time. Rarely, "west flow" flight patterns are used, when winds are so strong out of the northwest that aircraft only use the diagonal runways. Weather events in the form of storm cells commonly call for rerouting aircraft, exposing different people than usual to airplane noise.

In 2005, a consequential airspace change took place when DFW Airport switched from conventional to RNAV departures. This type of satellite-based navigation method uses very concentrated flight tracks, while reducing overall land area that is overflown as shown in Figure 6.4-6. This change reduced overflown land area by over 22 percent. Aircraft do fly over residential areas farther out from the airport, but the higher altitude of the aircraft by then reduces noise problems.

Communication is key within the airport's noise mitigation strategy. Engagement with local communities keeps the public informed of upcoming changes, such as a recent DFW runway closure. Also to support public engagement, DFW Airport's website offers a public tracker so people can track flights. The airport itself carefully watches flight tracks to understand unexpected flight patterns and address them when necessary.

Community noise complaints have been relatively steady for the airport over many years, but a huge spike occurred in complaints around 2021, when some gained the capability to file a noise complaint with the click of a button. Those complaints fell off quickly, and normalizing the equation by removing the few cases of a single person making multiple button pushes reveals record-low complaints recently. By drilling into the root causes of complaints, the airport can learn about ongoing community sensitivities and make changes where needed.

An internal newsletter keeps airport leadership informed. Also, the airport engages with the FAA in some cases—for example, when geofencing was set up to monitor flights on a particular runway that came under a land use ordinance— so flight paths could be adjusted when the geofences were being penetrated. (A geofence restricts flight paths to certain areas.)

With its current noise policy in place to aggressively limit noise exposure around its facility, DFW Airport is mindful that changes in U.S. policy could require updates to its noise policy. Potentially influential questions on the horizon include:

- Is DNL the right metric, and 65 DNL the right level?
- How will supersonic aircraft impact airport operations and noise?
- How will urban air mobility vehicles affect community noise levels?

Having concluded her presentation with this look ahead, Lancaster responded to a participant's question about monitoring versus modeling and how often the airport's results are compared. Generally, the measures are compared annually, with an interim consideration at six months if an unusual noise trend is identified. When discrepancies are identified the source of the problem is sought. The airport set up virtual monitors for a time to look at how modeling would compare to actual noise monitors, and they generally aligned.

Figure 6.4-1 Dallas Fort Worth Airport: Basic facts

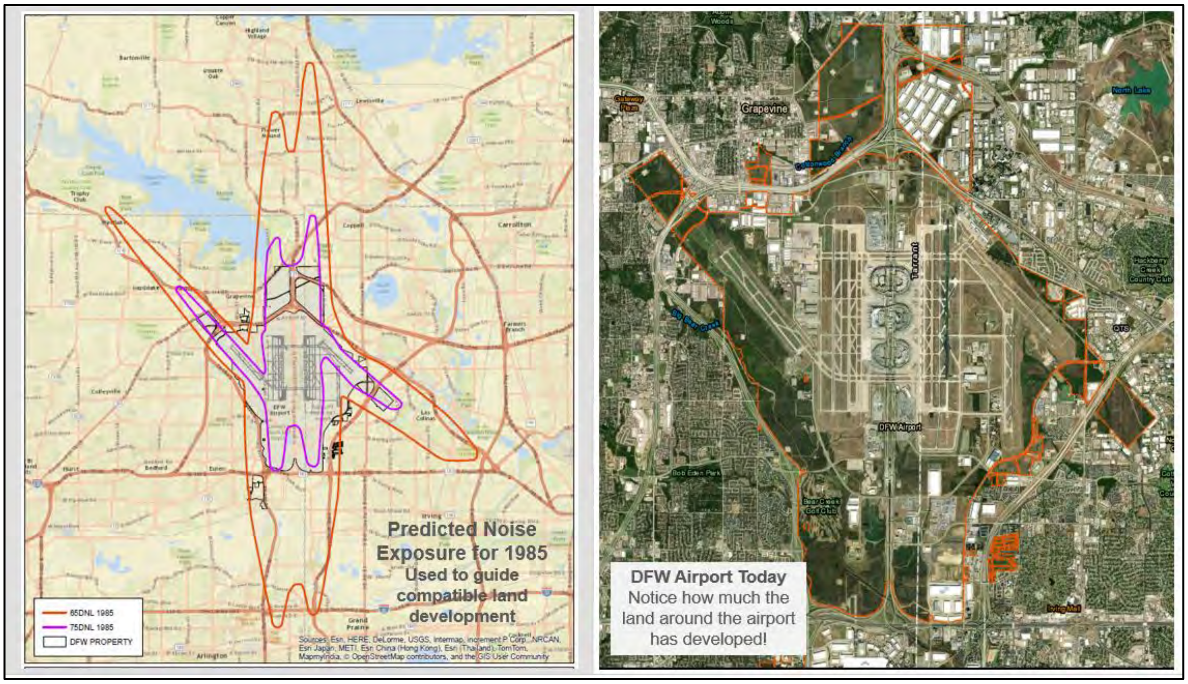


Figure 6.4-2 *Original noise exposure predictions were made in a very different era*

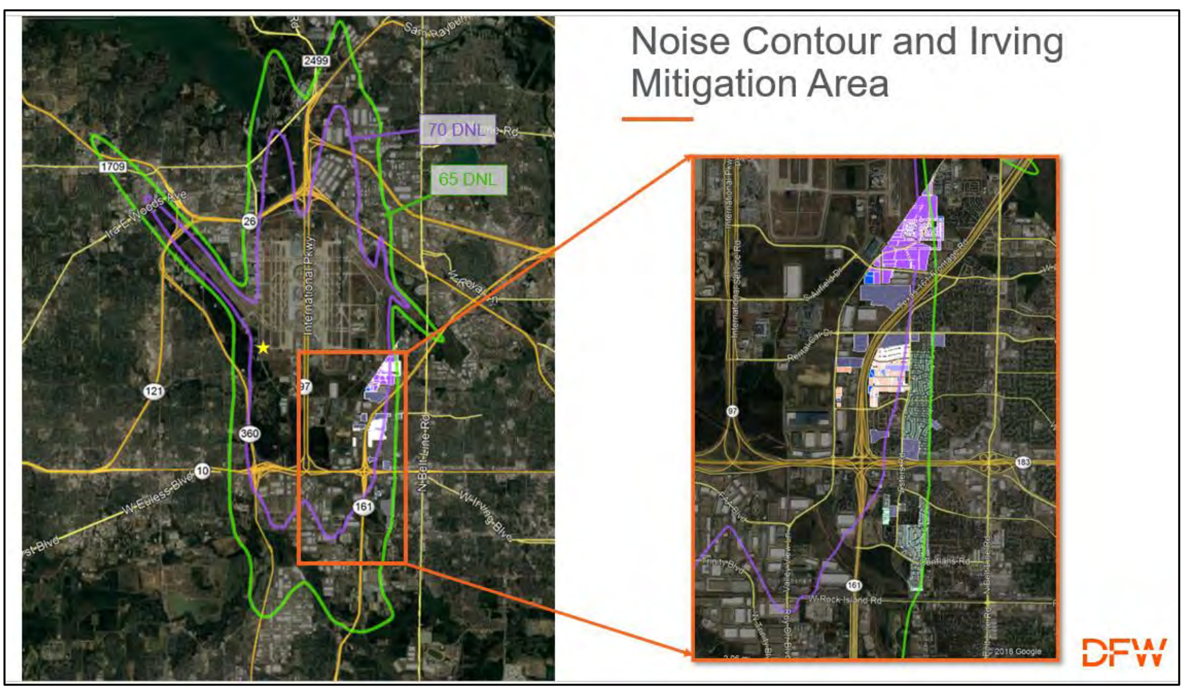


Figure 6.4-3 *Irving as an example of a completed mitigation area*

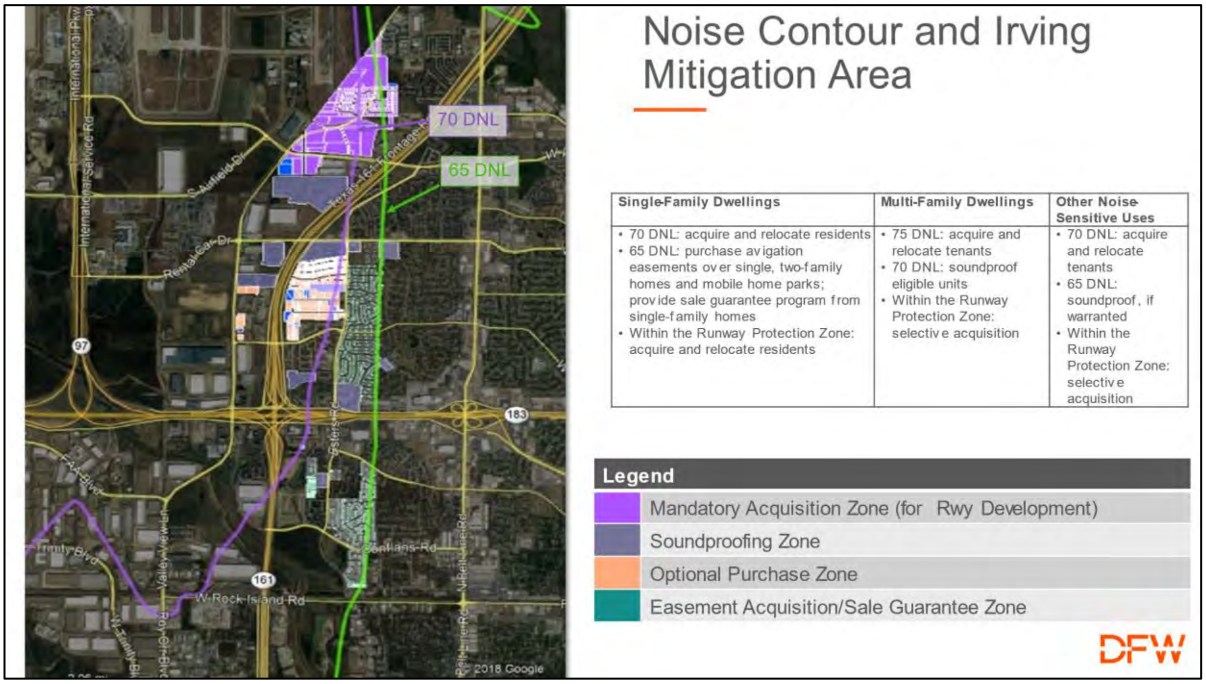


Figure 6.4-4 *Specific mitigation steps at Irving*

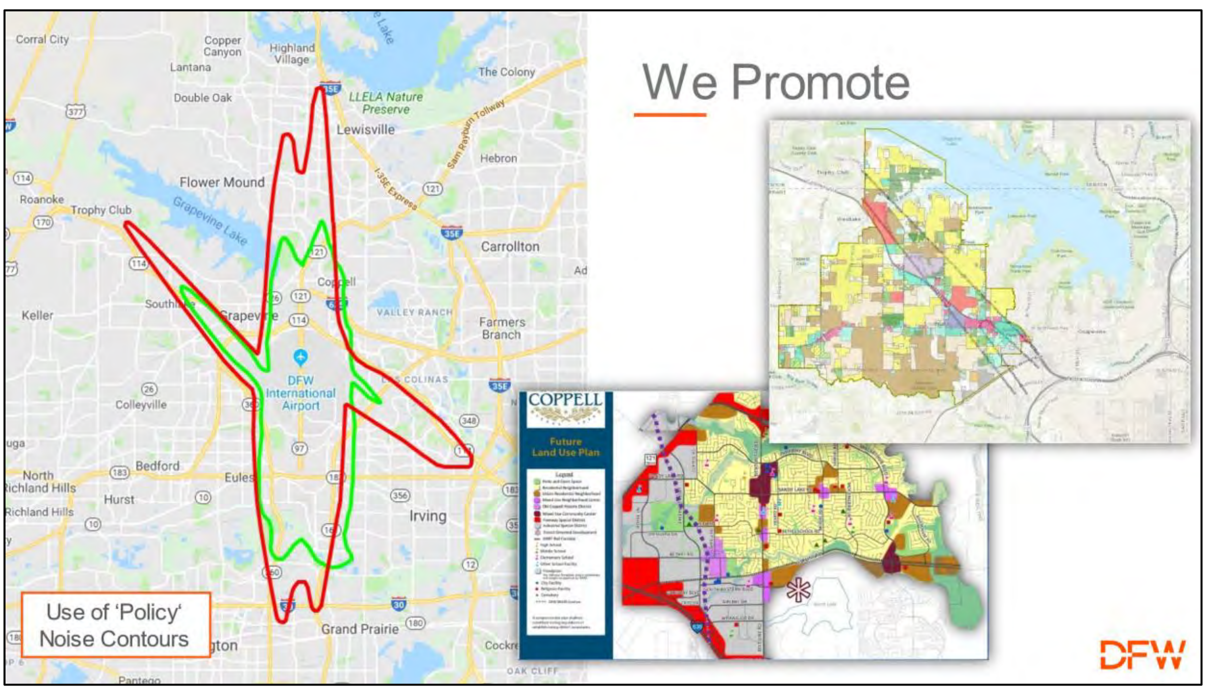


Figure 6.4-5 *Promoting compatible land use*

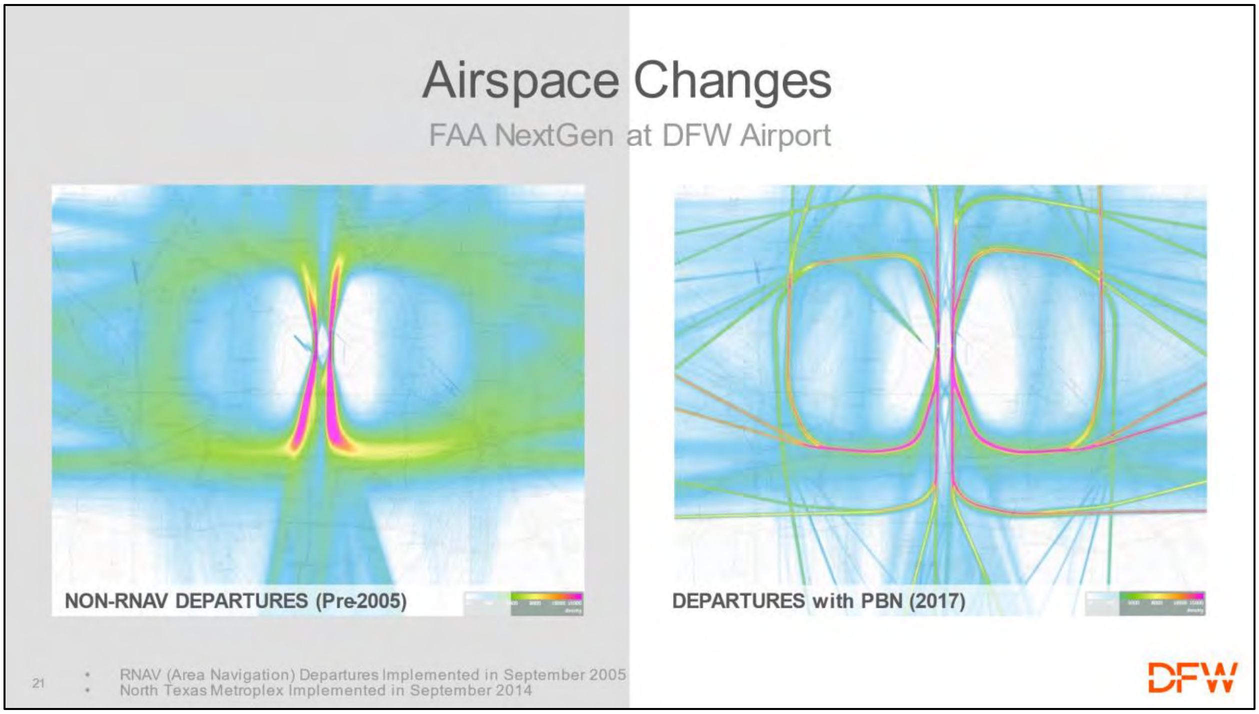


Figure 6.4-6 *Effect of flight paths before and after implementing RNAV*

6.5 Impact of Cargo Aircraft Operations at Memphis Airport

Terry Blue—Memphis Shelby County Airport Authority

Memphis International Airport—a busy hub for cargo delivery companies and notably FedEx—has no formal noise abatement procedures in place but has instituted effective informal noise control steps. Noise contours have shrunk for reasons including these procedures and FAA's updated navigation system and certification standards, and this airport, which represents an "economic engine" locally and for Tennessee generally, receives very few noise complaints.

Terry Blue, executive vice president for operations for the Memphis Shelby County Airport Authority, provided an overview of the Memphis International Airport and its cargo operations, in particular, and discussed noise at the airport, historically and currently.

The Memphis International Airport is depicted in Figure 6.5-1. It consists of four runways—three 9,000-foot runways and a new, 11,000-foot "World Runway"—within a space of nearly 4,000 acres. The airport served 4.2 million passengers and handled 4.5 million metric tons of cargo in 2021. This activity resulted in 215,000 annual operations. The typical aircraft mix consists of various single-aisle, narrow-body passenger aircraft such as the Boeing 737 and Airbus A320, along with several wide-body models in the FedEx fleet like the Boeing 757, 767, and 777.

The airport has an annual economic impact of $19 billion, and accounts for more than 83,000 jobs and nearly $5 billion in annual earnings in the region, according to a 2017 study. It is one of the largest economic engines in Tennessee, which gains it some deference in terms of community tolerance for noise, as will be discussed later.

Memphis International handles a huge amount of cargo, to the tune of 9.8 billion pounds in 2021 alone, with 110 to 120 daily departures during the day and 140 to 150 during the night. By itself, FedEx accounted for 99 percent of this cargo-related activity and made the airport the world's second busiest in terms of cargo in 2021.

Some highlights of the airport's history are summarized in Figure 6.5-2. FedEx relocated its headquarters to the airport from Little Rock, Arkansas in 1973, growing exponentially over time until its mega-package sorting complex became the "World Hub" it is today. In terms of passenger service, Memphis International grew into a dual hub when Republic Airways chose the airport as one of its hub locations. After Northwest Airlines acquired Republic in 1986, its passenger service at the Memphis Airport continued to grow, until the hub saw 300 daily flights at its peak. In 2008, however, Delta Airlines purchased Northwest, dropping Memphis as a hub in 2013. Today, the number of Delta departures has dwindled to just 20 per day.

During its time as a dual hub in the 1980s, the Memphis International Airport conducted an FAA-approved noise study. The efforts to reduce noise exposure resulted in a noise compatibility/property acquisition program, an FAA-approved project under which about 1,400 single-family residences were acquired that were located within a DNL 75-plus dBA noise contour. And in the early 1990s, the airport authority funded and led a joint-use planning program with surrounding governments that led to land use and zoning restrictions around the airport.

In 1989, 27 residential property owners filed a lawsuit, which later became a class-action lawsuit, seeking monetary damages and injunctive relief from the airport authority. The court action went through an evolution as summarized in Figure 6.5-3, and ultimately in 2004 the airport authority was required to make payment to over 12,000 claimants, with a total potential monetary benefit to the settlement class estimated at $22 million. Also as part of the settlement, aviation easements were granted over relevant properties in Tennessee and Mississippi.

The airport authority has followed up on the original noise study with periodic updates, and resulting noise exposure maps were accepted by the FAA in 2015 that represented a 2013 existing condition and a 2020 future condition. Noise contours surrounding the airport have shrunk over the years. Along with the FAA's implementation of satellite-based navigation and its application of stricter noise certification standards, modernization of the FedEx fleet from the older-generation Boeing 727 tri-engine aircraft to quieter twin-engine aircraft have also significantly reduced noise around Memphis International.

As for the noise picture today around the airport, no formal noise abatement procedures are in place, but several procedures have been developed informally, supported and adopted by Memphis stakeholders. The procedures include altitude and heading restrictions, as summarized in Figure 6.5-4, which help prevent the newer, high-performance aircraft from flying over sensitive residential areas as they depart the airport.

Memphis Airport operates a noise hotline for community members wishing to file a complaint about aircraft noise. Every complaint is researched to identify factors that may have played a role such as weather, traffic operations, or an anomaly. Despite the substantial number of FedEx flights, including many during the nighttime, the airport authority receives less than 100 noise complaints each year—many from the same individuals calling multiple times. Figure 6.5-5 provides a table of complaint numbers in recent years.

While other airports saw significantly decreased flight operations in 2020 due to the Covid pandemic, which would be expected to be associated with fewer complaints, Memphis International experienced significant operations in that year as FedEx shipped vaccines all around the world and met the spiked e-commerce demands. Another noteworthy phenomenon is that a low number of individuals in the community who are extra-sensitive to aircraft noise have increasingly made complaints to the airport, though they live several miles outside of the defined noise contours.

Credit goes to the Memphis-Shelby County Airport Authority team for their mitigation efforts in the 1980s and 1990s as part of the property acquisition and zoning efforts. Other important factors unique to the Memphis community are: the economic impact of FedEx, which employs nearly 30,000 people in the area; and the airport authority being associated with some 83,000 community jobs. "Those aircraft that operate in and out of the airport every night represent jobs and livelihoods for the Memphis community. In other words, cargo drives Memphis; it's in our DNA."

Looking ahead, the Memphis International Airport master plan forecasts a potential 25 percent increase in total operations, or a net increase of some 60,000 operations over the next 15 years. "The airport will need to stay connected to, and work with, the community so that we remain a good neighbor."

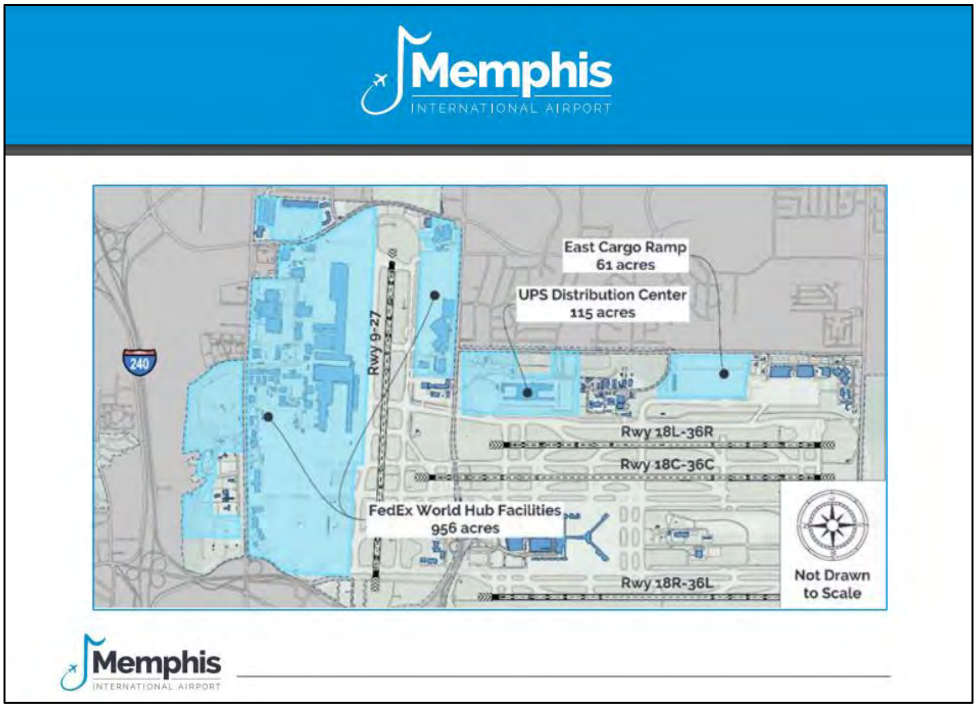


Figure 6.5-1 *Memphis International Airports basic layout*

Figure 6.5-2 *Cargo operations skyrocket while passenger service dwindles*

Lawsuit Results in Avigation Easements

- A lawsuit was filed against the MSCAA in 1989 by 27 residential property owners seeking monetary damages and injunctive relief; turned into a class action suit in 1993.
- In 1998, the Court redefined the class to include owners of improved real estates upon which there is a single-family residence, a duplex, or a condominium, within the areas identified on the Notice Map.
- Final judgment issued in 1998, approving the settlement of the class action. Judgement was appealed to the U.S. Court of Appeals for the Sixth Circuit where it was upheld in 2000.

Memphis

Lawsuit Results in Avigation Easements

- The case was closed in 2004 and required the MSCAA to make payment to 12,430 claimants. The total potential monetary benefit to the Settlement Class was estimated to be $22 million.
- An Avigation Easement was imposed on each Eligible Property in the State of Tennessee; Eligible Property Owners in Mississippi were required to grant an Avigation Easement before they qualified to receive payment

Memphis

Figure 6.5-3 *Evolution of lawsuit brought by area homeowners*

MEM Noise Program

No formal noise abatement procedures; however, the following are locally adopted procedures:

- Engine run-ups may only be conducted from 6:00 a.m. to 10:00 p.m., in the designated run-up areas.
- Turbojet aircraft shall turn or be given a heading which results in a turn below altitude 3,000 feet or north of Holmes Rd. to the south of MEM.
- Turbojet aircraft departing Runway 27 shall not be authorized to turn south until leaving 3,000 feet or two miles from the departure end.

Figure 6.5-4 *Locally adopted informal procedures for noise abatement*

Noise Complaints

	2017	2018	2019	2020	2021	2022
Total Noise Complaints	11	78	21	98	28	16
Total Complainants*	7	16	5	12	14	6

Noise Complaint Information
*MEM receives multiple complaints from the same residents.

Memphis International Airport

Figure 6.5-5 *Noise complaint numbers are low at this very busy airport*

6.6 Noise Situation at Hanscom Field

Amber Goodspeed—Massachusetts Port Authority

Hanscom Field, which is located outside of Boston, Massachusetts and borders the Minute Man National Park and Hanscom Air Force Base, serves primarily business jets. Rules for this suburban-area airport, including a nighttime field use fee, have minimized noise disturbance in the community. Hanscom has incorporated diverse systems for ongoing noise monitoring and reporting—including a database to analyze sound exposure levels and a "Fly Friendly" Touch and Go program—to minimize disturbance over sensitive areas.

Amber Goodspeed, manager of airport administration for Hanscom Field, shared her perspective on noise from this airport that serves mostly business jets. Located about 20 miles northwest of Logan International Airport in Boston, Massachusetts, the airport is nestled within suburban areas and borders the Minute Man National Historical Park and Hanscom Air Force Base.

Hanscom Field serves to reduce congestion at Boston Logan Airport. Its operations include a mix of commuter aircraft; business-use aircraft; charters including professional and collegiate sports charters; and light cargo, personal aircraft, air taxi, medical, military, and flight school activity. The airport offers U.S. Customs and Border Protection inspection services and provides facilities to receive global arrivals from various regions. The location is ideal to serve the diverse flying needs of the region's high technology corporations and educational institutions. The airport is also an important resource for Hanscom Air Force Base, which abuts the airfield. Hanscom has two runways, and hosts three fixed-base operators. The airport plays a crucial role in the local economy, with an annual economic impact amounting to $679 million, including support for 2,243 full-time jobs.

The airport has been supporting consistently increasing demand for business jet hangar space, undertaking various expansion projects to keep up with the need. Additional hangars reduce the need to ferry aircraft in and out of Hanscom, reducing the number of overall flights and thereby decreasing environmental impacts in terms of noise and air quality.

Policy, regulatory, and planning documents under which Hanscom Feld operates are listed and described in Figure 6.6-1. Guiding documents include the 1978 Hanscom Field Master Plan and the Commonwealth of Massachusetts 1980 General Rules and Regulations for Hanscom Field, which sets important conditions influencing Hanscom operations. Among these rules is a 60-seat limit for commercial passenger services. As the current business model for passenger jets calls for larger aircraft with longer-range capabilities, no operators currently seek to operate commercially at Hanscom Field.

Among these rules a nighttime field use fee has been in place since 1980 that assesses an additional fee for landing between the hours of 11 p.m. and 7 a.m., with the fee doubling after five nighttime operations in a calendar year. With operators aiming to minimize these nighttime fees, fewer than 2,500 nighttime operations occur annually, which accounts for less than 2-1/2 percent of annual operations.

Fortunately for area residents, the nighttime rule and other limitations on nighttime operations were in effect before enactment of the Airport Noise and Capacity Act of 1990 (ANCA). ANCA handed over the regulatory authority to govern airports previously a local responsibility to the FAA for national oversight.

This prevented use of different rules across municipalities. These days, a new stipulation of this type would not be possible.

The Environmental Status and Planning Report (ESPR) is a document prepared every five years that examines possible environmental impacts for the study year—most recently, 2017—and forecasts 10 to 20 years into the future. The document serves as an environmental impact report and also a master planning document for the airport. The next report, the 2022 ESPR, is expected to be published in 2023.

Hanscom has six noise monitors: four are located at each of the four surrounding communities near the runways' ends, and two noise monitors are located on the field. The public has the ability to pull reports from these monitoring terminals at any time.

Hanscom publicly reports monthly aircraft activity and noise as measured by its monitoring system, as well as information about construction activities. Also, in addition to an Annual State of Hanscom report detailing the previous year's operations, upcoming capital programs, and financial performance, Hanscom publishes an annual Noise Report that details noise and operations by type and noise exposure levels.

In the early 1980s, interested area citizens, Massport officials, and acoustical consultants Harris Miller Miller & Hanson defined a metric for routinely evaluating the effects of changes in the aircraft fleet mix and the number of operations. The "EXP" database management system developed to calculate the metric represents a tool for comparing civilian noise to military noise, and compares changes in total noise exposure month to month and year to year. EXP applies the same methodology used for calculating DNL, and applies nighttime noise penalties to create a sound exposure level for each aircraft in the fleet.

Specifically, in the calculation of EXP, each aircraft type is assigned to a group based on size, the number and type of engine, climb performance, and ultimately, noise level characteristics. Using FAA noise and performance data, arrival and departure sound exposure levels (SELs) are assigned to each group. The SELs used for EXP represent the amount of noise generated 15,000 feet from start of take-off roll.

Total departure noise exposure on an average day is calculated for each group by:

1. Logarithmically multiplying the representative SEL for the group by the average number of departures by those aircraft, weighting the nighttime operations, and creating a "partial" departure EXP; and
2. Logarithmically adding all "partial" EXPs for the entire fleet to obtain a single number estimate of departure noise exposure.

By use of its sophisticated noise assessment tools and through extensive community outreach, Massport strives to build positive community relations and public confidence on behalf of Hanscom Field. Community outreach activities include monthly community meetings that include industry experts as well as representatives from each local town; advertisements to share relevant news; and a website that allows the public to investigate airport activity, raise concerns, and produce their own noise monitoring reports.

Reports of noise disturbances from Hanscom are reviewed in various ways, such as by examining how many households reported disturbances during the month and from which towns. For example, in a recent month, there were 252 callers from 25 households in nine different communities.

Operations at Hanscom Field have decreased 67 percent from a high of 300,000 operations in 1970 to under 100,000 operations in 2020, and noise exposure has likewise fallen during this period. Reductions in fleet noise, due to reduced operations, regulatory changes, and other factors, have consistently kept the 65 DNL contour largely on airport property, and therefore Hanscom Field does not have a sound insulation program.

Despite the decrease in households within the 65 DNL to zero today, however, noise complaints have increased by more than 900 percent since 2012. The primary reason: the introduction of the "Air Noise button", which is the method by which 85 percent of complaints have come in over the past couple of years.

Single Engine Piston activity, including Touch and Go activity, makes up about 60 percent of total airport operations. The "Fly Friendly" Touch and Go Program, as summarized in the program brochure reproduced in Figure 6.6-2, is an effort with the Minute Man National Historical Park to reduce touch and go traffic disturbances over sensitive areas. "Safety is our number one priority and flying friendly comes next."

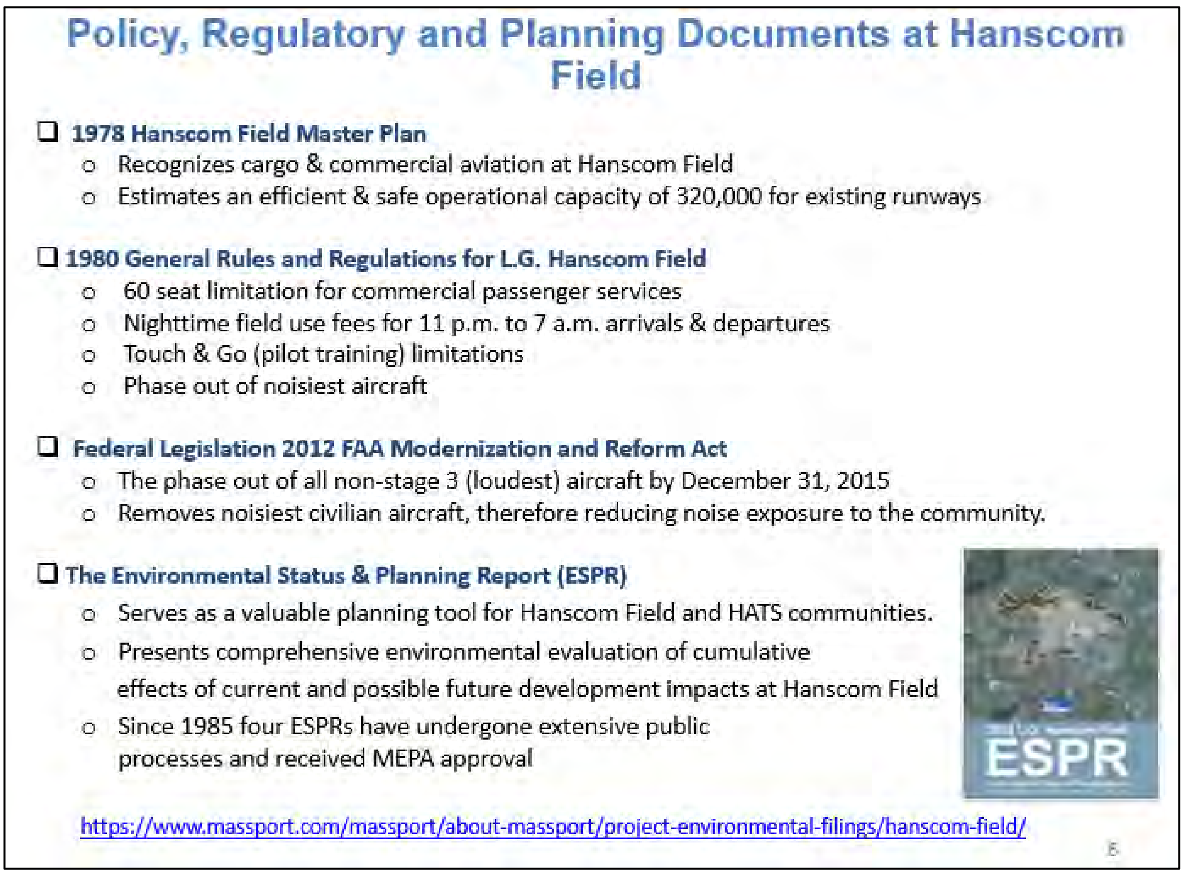


Figure 6.6-1 *Documents guiding Hanscom Field Airport operations*

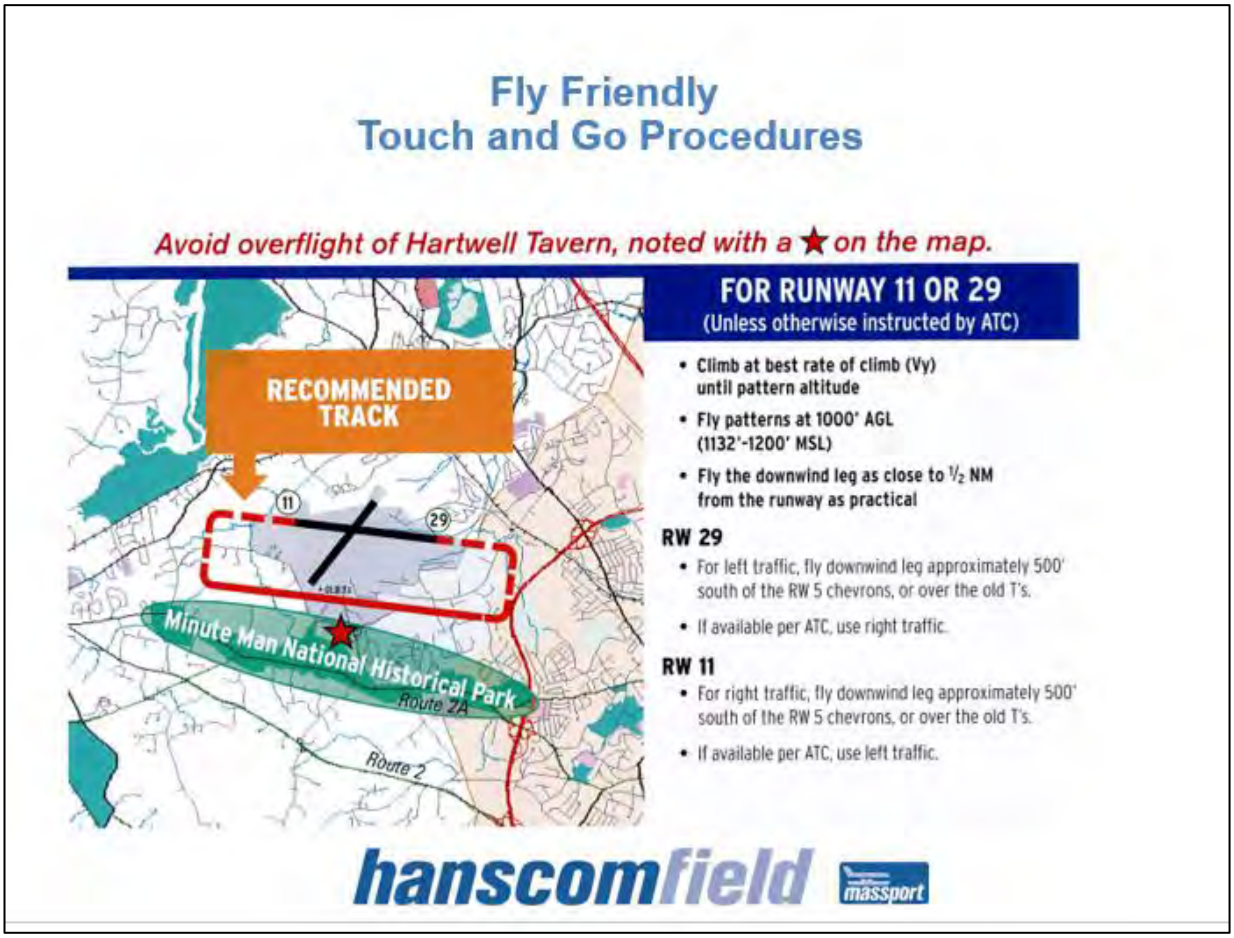


Figure 6.6-2 *Fly Friendly Touch and Go procedures reduce disturbances in sensitive areas*

7.1 Keynote Address: Aircraft Noise in Japan—Past, Present and Future Challenges and Strategies for Increasing Community Acceptance

Naoaki Shinohara—Aviation Environment Research Center, Japan
Makoto Morinaga—Kanagawa University, Japan

Japan has long implemented measures to address noise around its airports. With increasing demand for air transportation, including nighttime flights, the country must continually reconsider best approaches for reducing noise levels and also lessening annoyance through non-acoustic measures.

Naoaki Shinohara, an aircraft noise researcher with Japan's Aviation Environment Research Center, opened the presentation about Japan's experience with aircraft noise and community response by speaking about historical and current challenges and corrective measures.

Japan has taken action to address aircraft noise since the 1970s, and since 2001 has implemented measures in keeping with the ICAO's Balanced Approach to Aircraft Noise Management. Measures taken by Japan fall into three main categories: reducing noise at the source, improving airport structure/facility, and taking mitigation measures. These categories and associated control strategies—including the introduction of low-noise aircraft, restrictions on night flights, construction of offshore airports, and remedial compensation for actions such as soundproofing of houses—are presented in Figure 7.1-1.

Aircraft noise around Japan's major airports has been a serious problem since the 1960s, following the introduction of jet aircraft. In Japan's urban Osaka and Tokyo airports, jet noise caused serious social problems and resulted in lawsuits seeking both compensation and a ban on nighttime flights. To this day, restricted nighttime hours are in effect. Also, to address capacity issues in certain areas of Japan in the 1960s, the new Tokyo (Narita) Airport was located in an inland area, leading to fierce opposition. When the airport, in the plans since 1966, finally opened in 1978, it had only one runway and nighttime curfew hours.

In 1973, environmental quality standards for aircraft noise were enacted, and the law for remedial aircraft noise measures was therefore amended to cover subsidies for insulating private homes. Also, the government built an offshore airport to address the noise problem in Osaka.

In the 1980s and 1990s and beyond, new remedial measures were initiated and others continued in effect. These steps included soundproofing around several airports and offshore locations for some airport operations, as summarized in Figure 7.1-2 along with previous decades' measures.

Noise problems seemed to lessen following changes in the 1990s such as the introduction of low-noise aircraft like the Boeing 777 and construction or relocation of airports to offshore locations. About 10 years ago, however, complaints began to increase at areas far from the airport exposed to low-level noise and frequent flyovers.

Japan has taken various approaches to noise mitigation. The Aircraft Noise Prevention Law (ANPL) designated 14 airports with significant noise impact. Depending on LDEN, measures put in place included improvement of purchased land to green buffer zones, purchase and removal of houses, and subsidies for soundproofing of homes as well as schools and hospitals. These measures are summed up in Figure 7.1-3.

Most airports were designated as noise control zones in the 1970s, after which no compensation was provided for those newly residing in the areas around these airports. The law restricting land use around airports, the Special Act for Aircraft Noise Prevention, was created to prevent new residents from moving into areas affected by airport noise. It was applied only to Narita Airport, which opened in 1978. The law provides for remedial measures depending on zone designation according to LDEN levels.

The government's budget for environmental measures related to noise around civil airports is shown in Figure 7.1-4. Investment was concentrated in an approximately 10-year period, reaching a high point around 1980 when investment amounted to about 102 billion yen per year, mainly for soundproofing. By 1985, more than 90 percent of houses covered by the program had been soundproofed. By 2016, the cumulative cost of these measures reached 1.4 trillion yen. Since 2010, government investment in these types of environmental measures has been drastically reduced. (Note: 1000 y ≈ 7.5 USD in April 2023)

Compensation in forms including soundproofing subsidies for houses were intensively implemented until around 1985. Since the 1990s, new airports have been constructed off-shore which, in combination with other measures, has helped manage noise problems. Noise reduction has been achieved through collaboration among airports, local governments, and communities.

In terms of changes in aircraft noise over time, single maximum noise events have decreased by 8 to 12 decibels over a 35-year period. That equates to an average decrease of 0.2 to 0.3 decibels per year—even as flight frequency more than doubled over the same time frame.

A growing demand for air transportation has led to the construction and expansion of runways, introduction of new flight routes, and relaxation of nighttime curfews. To address increased transportation demand while considering noise issues, two airports (Sapporo and Sendai) have expanded their noise control zones and implemented bedroom soundproofing measures beyond the requirements under the Aircraft Noise Prevention Law (ANPL), in exchange for permission for 24-hour operations.

Tokyo's Haneda Airport has the largest number of flights in Japan, with the Narita International Airport helping to address demand in the Tokyo area. In 2010, with an additional runway operating and changed flight loads at the Haneda Airport, complaints rose in the area of Chiba that is far from the airport. To address this, the use of sea routes to avoid residential areas was among the measures implemented.

In the last couple of years, the Civil Aviation Bureau, which manages Haneda Airport, has held many community briefings in areas around the airport as capacity expands. Additional measures put in place include the use of steeper, area navigation (RNAV) approaches. The noise burden has been reduced slightly in the Chiba area, with noise newly shared by an additional downtown landing route, but meanwhile complaints have been made by those under the new route.

The Narita Airport has built trust with area residents through a combination of extensive communication with those in the community and implementation of careful noise countermeasures that reach beyond legal requirements. The airport is stepping up these types of measures—for example, providing extra bedroom soundproofing to lessen sleep disturbance—as it implements an expansion plan in anticipation of future aviation demand. Additional efforts will be needed as the airport extends and constructs runways and relaxes nighttime flight restrictions. While nighttime hours will be different from airport to airport, quiet hours will be kept to seven hours.

Demand in Japan for domestic overnight flights is low and Japan has effectively reduced sleep disturbance around airports by restricting night flights. But demand for late-night flights has increased recently due to a demand for cargo flights and international passenger flights. As some airports begin to relax their nighttime restrictions, residents have concerns about their sleep being disturbed. An agreement has been reached with residents to address expanded nighttime flights with more countermeasures and, for its part, the Narita Airport is conducting a survey of residents to confirm that the relaxation of the nighttime curfew is associated with health problems.

Next, Makoto Morinaga, a researcher and assistant professor at Japan's Kanagawa University, spoke about community response to aircraft noise in Japan and possible ways to increase noise acceptance.

While communication with area residents and mitigation measures seem to have been effective, social surveys actually indicate that noise annoyance response has become more severe in the 2000s compared with the 1990s. This is reflected in Figure 7.1-5 showing changes in community annoyance over time. The dotted lines reflect the results of four studies conducted in Japan, and the solid lines show the FAA, WHO (World Health Organization), TNO (Netherlands Organization for Applied Scientific Research), and Federal Interagency Committee on Noise (FICON) curves.

Figure 7.1-6 shows the exposure-response relationship based on the average values of two social surveys conducted after 2000. These studies suggest that current environmental quality standard values of 57 decibels and 62 decibels correspond to highly annoyed percentages of 40 and 50, respectively.

Especially in light of apparent increased annoyance in recent years, environmental quality standards for aircraft noise in Japan—which have not been updated for about 50 years—should be re-examined. In addition to working to reduce noise exposure, a strategy is needed to increase community acceptance of noise.

While direct measures of noise exposure are extremely important, attention should also be paid to non-acoustic factors. In this context, holding continual meetings with those living near an airport is "essential" if residents are asked to bear the burden of noise. Such communication has been shown to be effective in the past, and current efforts to include residents in relevant discussions fall short and should be bolstered.

Existing subsidies for local municipalities to improve the living environment near airports—by building public facilities such as parks and schools, for example—also show promise for reducing annoyance. Research looking at such non-acoustic measures includes a case study that examined satisfaction around a military airfield with these types of living environment improvements as non-acoustic measures for reducing annoyance. Non-acoustic factors are addressed in Figure 7.1-7 along with measures to reduce direct effects.

In Figure 7.1-8 charting results, the x-axis represents noise exposure (WECPNL) and the y-axis indicates degree of annoyance. The red line represents the exposure-response relationship for people not satisfied with the measures, and the blue line represents the same for satisfied people. In areas around military airfields, with high noise exposure, satisfaction with improvements in the living environment was not related to degree of annoyance. On the other hand, in areas with lower exposure, the degree of annoyance was lower among those who were satisfied with the improvements.

Based on these results, objective noise reduction should be the priority in areas of very high exposure. On the other hand, non-acoustic measures such as improving the living environment may have an important impact in relatively quiet areas. Additionally, it may be worth investigating whether non-energy-based metrics should be introduced.

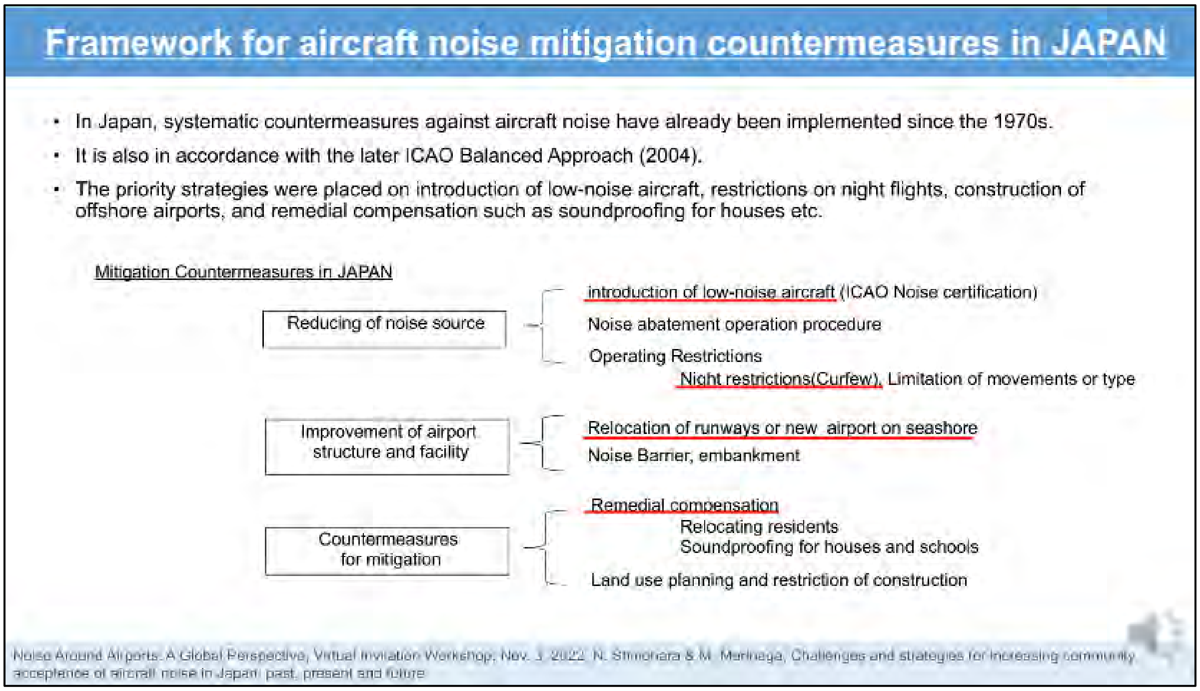


Figure 7.1-1 *Overview of Japan's aircraft noise mitigation approaches*

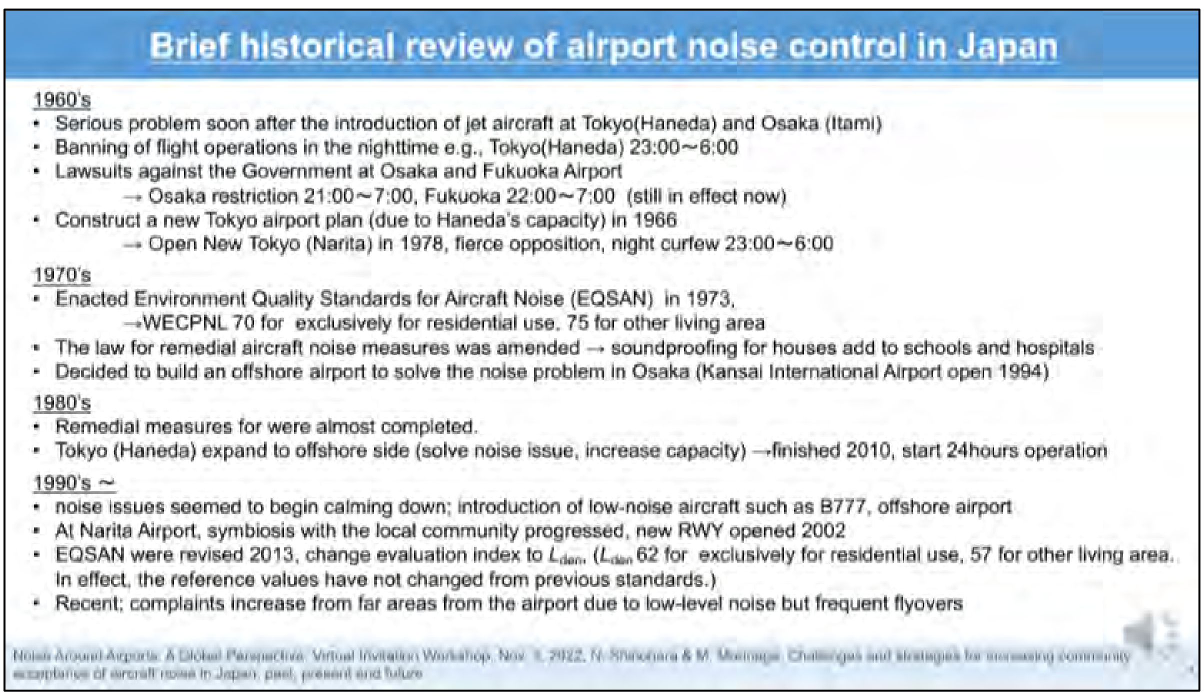


Figure 7.1-2 *Airport noise control in Japan, over the decades*

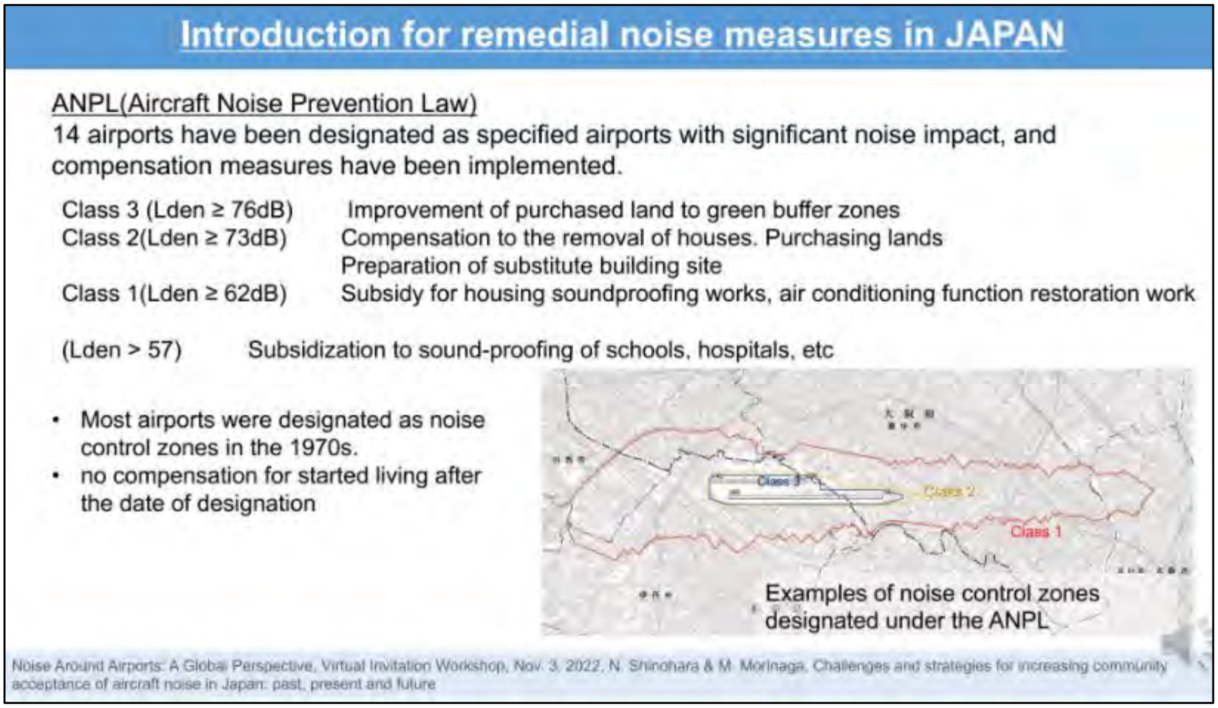


Figure 7.1-3 *Classes of noise remedies under the Aircraft Noise Prevention Law*

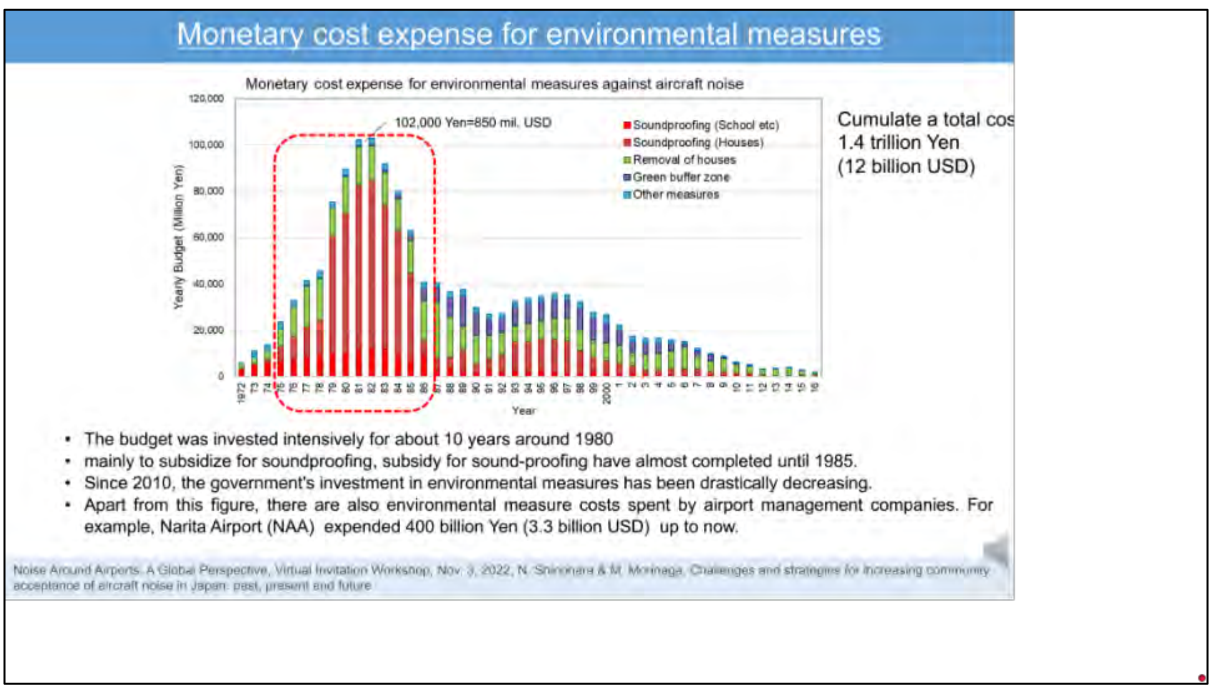
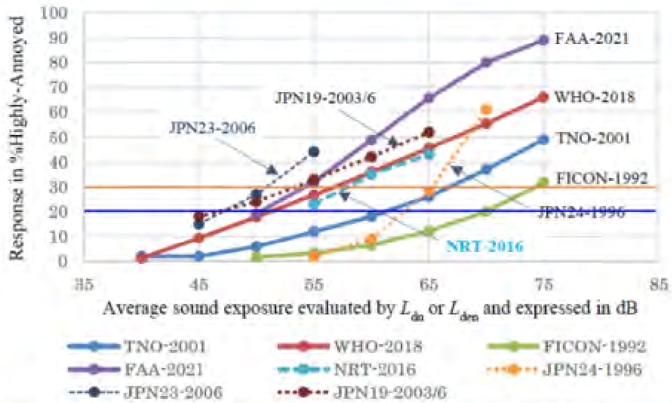


Figure 7.1-4 *Investment in environmental measures*

Change in community annoyance over survey ages

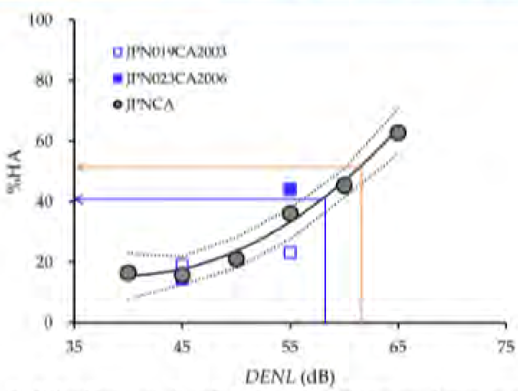


I. Yamada, "Viewing the changes in community annoyance due to aircraft noise over the times", Inter-Noise 2022

Data set	%HA 10	%HA 15	%HA 20	%HA 25	%HA 30
JPN019 (2003)	—	—	46 dB	50 dB	53 dB
JPN023 (2006)	42 dB	45 dB	47 dB	49 dB	51 dB
JPN024 (1996)	60 dB	62 dB	63 dB	64 dB	65 dB

Figure 7.1-5 *Surveys show changes in community annoyance over the years*

Representative exposure-response relationship



S. Yokoshima, et al., "Representative Exposure–Annoyance Relationships Due to Transportation Noises in Japan", IJERPH, 18, 10935 (2021).

Japanese Environmental Quality Standard for Aircraft Noise

Category of area	Standard value
I	57 dB
II	62 dB

Area category I: used exclusively for residential purpose.
Area category II: other areas where the normal living conditions shall be preserved.

Based on the standard values enacted before almost 50 years ago.

Data set	40 dB	45 dB	50 dB	55 dB	60 dB	65 dB
JAPAN	16.5%	15.8%	21.1%	36.2%	45.4%	62.8%
FAA	5.5%	10.5%	19.1%	32.1%	48.8%	65.7%

Noise Around Airports: A Global Perspective, Virtual Invitation Workshop, Nov. 9 2022, N. Shinohara & M. Morinaga: Challenges and strategies for increasing community acceptance of aircraft noise in Japan: past, present and future

Figure 7.1-6 *Representative exposure-response relationship*

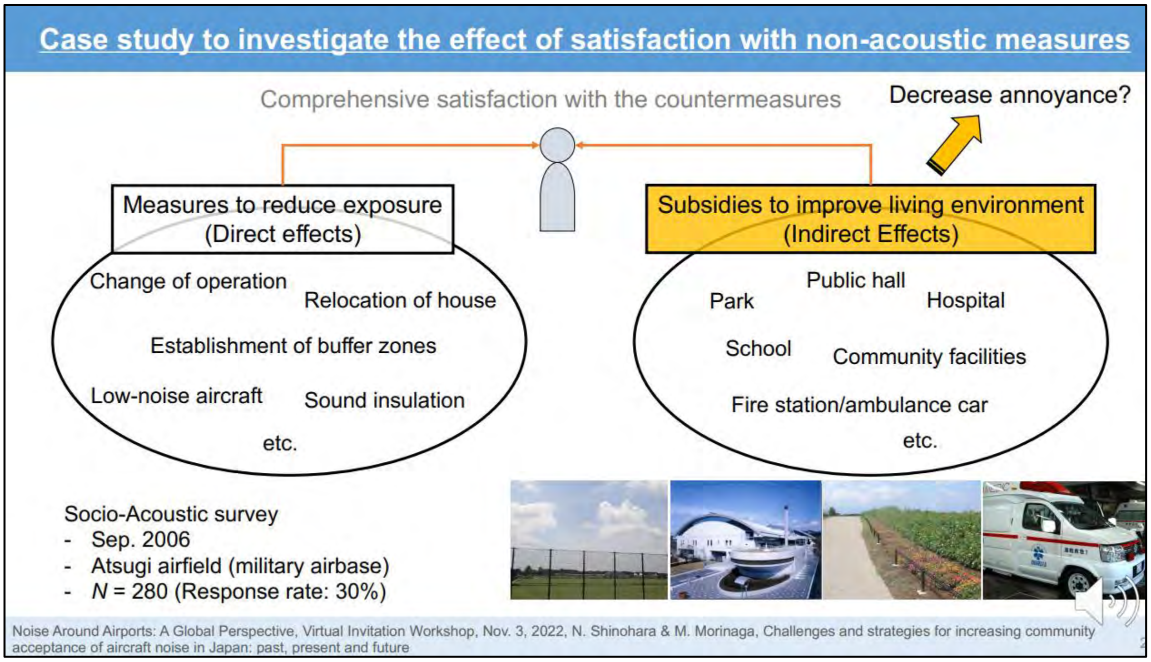


Figure 7.1-7 *Studying the impact on annoyance of non-acoustic changes*

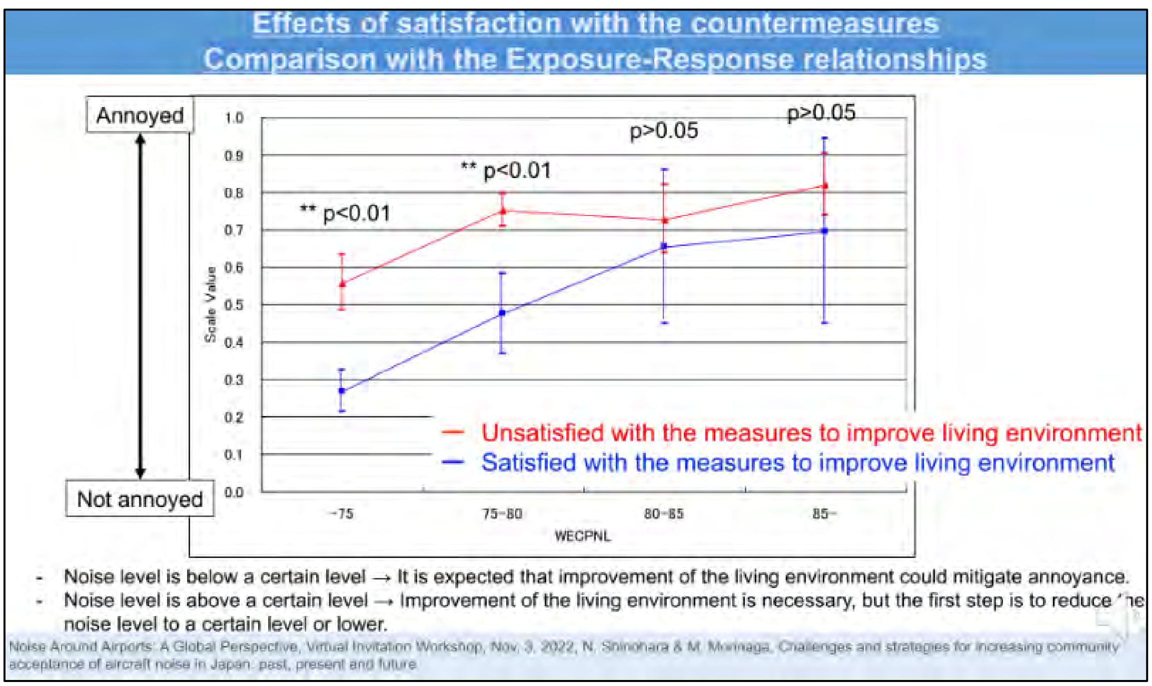


Figure 7.1-8 *Does satisfaction with living environment improvements affect annoyance?*

7.2 Aviation Noise Is Not Only an Engineering Challenge

Laurent Leylekian—ONERA

The goal of the ANIMA project was to address the challenge of managing aviation noise as a democratic process in which all stakeholders are empowered to contribute their perspectives. In recognition of the limitations of engineering advances for reducing noise around airports, the ANIMA project was designed to develop complementary methodologies, approaches, and tools to manage aviation noise and annoyance.

Laurent Leylekian, with the French national aerospace research center ONERA, spoke about the EU Aviation Noise Impact Management Through Novel Approaches (ANIMA) research project, on which he served as coordinator, and the broader issue of the challenge of managing aviation noise. Leylekian first presented some background on aviation noise in Europe and then discussed ANIMA's objectives and outcomes, as well as the noise management-related tools developed through the project.

As detailed in the European Environmental Agency's *European Environment—State and Outlook 2020 report*, the number of people affected by aviation noise is negligible relative to those affected by other types of noise, including that from rail and road transportation. The report's cover features an aircraft, however, reflecting the cognitive dissonance between the fact that most people in Europe are not impacted by aviation noise and the sense that aircraft are an important source of noise in Europe.

Figure 7.2-1, with information from the same 2020 report, shows a greater number of people report higher annoyance from a given year-averaged level of noise (Lden) from aviation relative to the same Lden from rail or road transportation. And during the night, a higher number of people report their sleep is highly disturbed when noise is coming from aircraft, despite the same objective year-averaged night noise levels (Lnight).

The World Health Organization (WHO) guidelines for the European region indicate a correlation between noise at certain levels and disability-adjusted life years (DALYs), which are the number of years one lives in good health. WHO found that those in Europe lost hundreds of thousands of disability-adjusted life years, collectively, from sleep disturbance as well as from "annoyance." These numbers, along with the numbers of disability-adjusted life-years lost to physiological conditions such as ischemic heart disease, children's cognitive impairment, and tinnitus, are listed in Figure 7.2-1. "So this is not marginal annoyance, but health issues we're talking about." With aviation noise deemed to be more annoying than other types of transportation noise, WHO provided substantially more stringent noise level recommendations relating to aviation compared to road or rail.

The four-year ANIMA project was launched in 2017 in response to this important issue of annoyance from aviation noise. The overarching objective was to develop methodologies, approaches, and tools to address the impact of aviation noise, while enhancing the capability to respond to a growing demand for air travel. The broad consortium brought together 22 partners, including airports, from 11 countries.

Objectives included:

- Understanding how noise impact is managed today by airports and aviation authorities, and how different levels of regulation are handled and implemented;
- Enhancing the understanding of the various aspects of noise impacts (such as annoyance, health, and quality of life) and especially the understanding of non-acoustical impacts; and
- Providing tools for aircraft designers and noise experts, as well as non-specialists.

Notably, ANIMA was a "human-centric" project, not a technology-oriented project dealing with issues such as noise reduction at the source. The project's main product was a methodology to support airport authorities wanting to implement noise-related improvements.

The methodology is based on a "transparent" and "democratic" decision-making process that involves all stakeholders—such as noise-affected communities, aviation policymakers, airports, airlines, employees, and the flying public—and not just the most vocal ones. Communication within this process should be undertaken using an accessible "common language" rather than jargon or expert language.

Using this type of fair, inclusive, and transparent process, stakeholders work toward points of consensus, prepared to accept and endorse the outcomes. A consensus is not a solution as a solution pleases everyone whereas consensus balances the detriments among all. Once a decision is made and an approach implemented, a monitoring process should be in place to allow for feedback and possible adaptations as necessary.

The "Noise Platform" captures the ANIMA-compiled knowledge and know-how related to aviation noise and related annoyance. (See https://anima-project.eu/noise-platform/main-page.) The platform provides noise management tools and features dynamic noise maps, Twitter semantic analysis, and noise management software.

One tool, dynamic noise maps, represents an alternative to traditional static noise maps. The central concept underlying this dynamic approach is that it takes into account the different locations of populations at different times of day—in the house versus at work or school, for example. Figure 7.2-3 illustrates the concept through a dynamic noise map of the area surrounding Serbia's Belgrade Airport. Whereas a traditional noise map considers noise exposures only at residential locations, the dynamic one considers populations' daily mobility patterns. Based on statistical population flows, dynamic noise maps provide models to compute who is impacted by high noise levels during various time slots. Yellow dots are used in Figure 7.2-3 to represent the locations of the population at a given hour.

The data, in combination, can support analysis of the impact of noise on a population. Figure 7.2-4 presents conclusions that can be drawn with the use of dynamic noise maps. For example, the number of people annoyed is shown in the dynamic scenario to increase by 2.9 percent compared to the static scenario, while the number of people who are highly annoyed decreases by 10 percent according to the dynamic measure. No difference is seen in terms of sleep disturbance, as people generally remain in their homes overnight.

This type of simulation could be done for each hour, with traffic as a possible factor used by policymakers to indicate movement around an area. The information has the potential to inform regulatory frameworks.

A second tool developed within ANIMA is the Twitter semantic analysis, which aims to capture expressions on the social media platform of opinions related to airport noise. Twitter was selected because input is hashtagged and can be localized, and users can be identified. The platform provided an application programming interface (API) to allow the retrieval of, and engagement with, various resources such as tweets. When faced with Covid-related challenges, with limited traffic and traffic noise, the ANIMA team was able to rely on past, archived tweets.

Challenges with this Twitter-based analysis included assessing the relevance of the tweet to noise actually around the airport and extracting the intended meaning behind each sentiment, especially when a statement was not obviously positive or negative but could be relying on sarcasm or a euphemism, for example.

The ANIMA team was able to post process the data into a temporal analysis to extract the number of positive, negative, and neutral tweets during each hour of each day. And they were able to localize the tweets by positive or negative statements using geospatial analysis. Moving forward, the group wants to compare this dataset with others such as ones from TripAdvisor and Airbnb, provide a toolkit to various airports, and compare results with more traditional surveys. The analysis has been performed around London Heathrow where most tweets are in English but can be adapted to other locations with other languages.

The noise management toolset, another instrument developed as part of the ANIMA project, is designed to compare noise maps and annoyance indicators. This measurement toolset is set apart from other similar tools by its capability to semi-empirically simulate noise sources of future aircraft designs or aircraft parts (such as engines). The toolset also features a wide range of metrics, and the "receiver state" can be adjusted for various scenarios based on factors such as demographics, home insulation status, and flight traffic shifts.

The toolset exists in two versions: the Public Noise Toolset for educational purposes, showing the product's potential using "pre-cooked" scenarios with a virtual airport; and the full-fledged Noise Management Toolset, for airports and aviation authorities, that allows for the importation of detailed parameters related to factors such as airport operations and surrounding populations' sensitivity levels (for instance through dose-response curves).

Figure 7.2-5, showing results of an air traffic simulation with small medium-range blended wing body aircraft in Mallorca, Spain, offers an example of this promising toolset in use. One can clearly see that the noise contours that were quite wide for a given decibel level with traditional small medium-range aircraft shrank significantly when those aircraft were replaced by blended wing aircraft.

Figure 7.2-6 shows another sample simulation, in Budapest, with night traffic in the 10 p.m. to 6 a.m. window shifted to the 11 p.m. to 7 a.m. window. On the assumption that people are sleeping from 10 p.m. to 6 a.m., the traffic shift does not change the number of people who would be awakened (awakening maps are shown on the left side of the figure), but if, instead, people are sleeping from 11 p.m. to 7 a.m., the traffic shift to 1 hour later substantially reduces the number of people woken from their sleep (awakening maps on the right side of the figure).

This tool's versatile dataset, accessible on the ANIMA website, could be enriched by the incorporation of additional non-acoustical indicators. The tool could also benefit from testing by airports and aviation authorities.

In conclusion, ANIMA does not deliver a one-size-fits-all methodology, but rather provides a framework to cope with the impact of aviation noise. "The ANIMA methodology aims to help communities, airports, and authorities that wish to improve their noise situation but don't know where to start in their quest for consensus." In addition to the results that are available on the ANIMA website, at https://anima-project.eu/ , the book *Aviation Noise Impact Management* can be downloaded free of charge, at https://doi.org/10.1007/978-3-030-91194-2.

In the broad context of aviation noise, it is worth noting that, while engineering promises to help reduce aviation noise through approaches such as noise reduction technologies and noise abatement procedures, increases in traffic and background noise are significantly undercutting these types of technological steps forward. Also, measurement of human impact from noise with the use of intensity-based metrics does not appropriately account for feelings of annoyance.

An important factor in addressing these issues for the protection of communities near an airport is the empowerment of people who are affected—an empowerment that comes from their trust of local democratic processes. “I hope that, in this regard, the ANIMA methodology may help.”

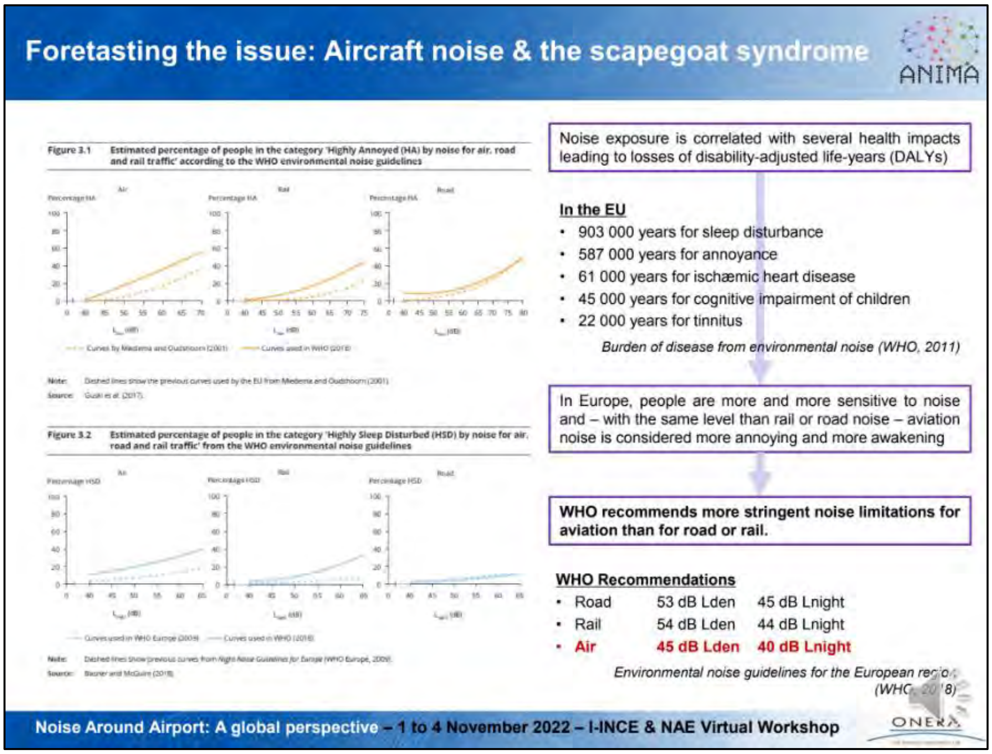


Figure 7.2-1 *People report greater annoyance from aviation noise than other types of noise*

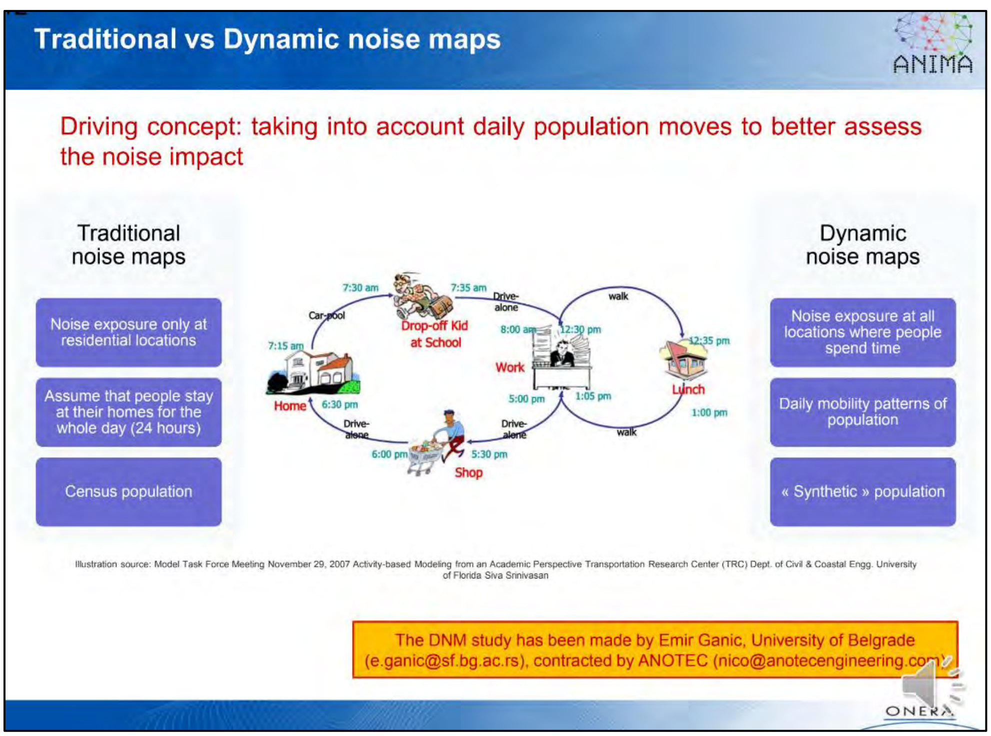


Figure 7.2-2 *Dynamic noise maps consider how the population moves throughout the day*

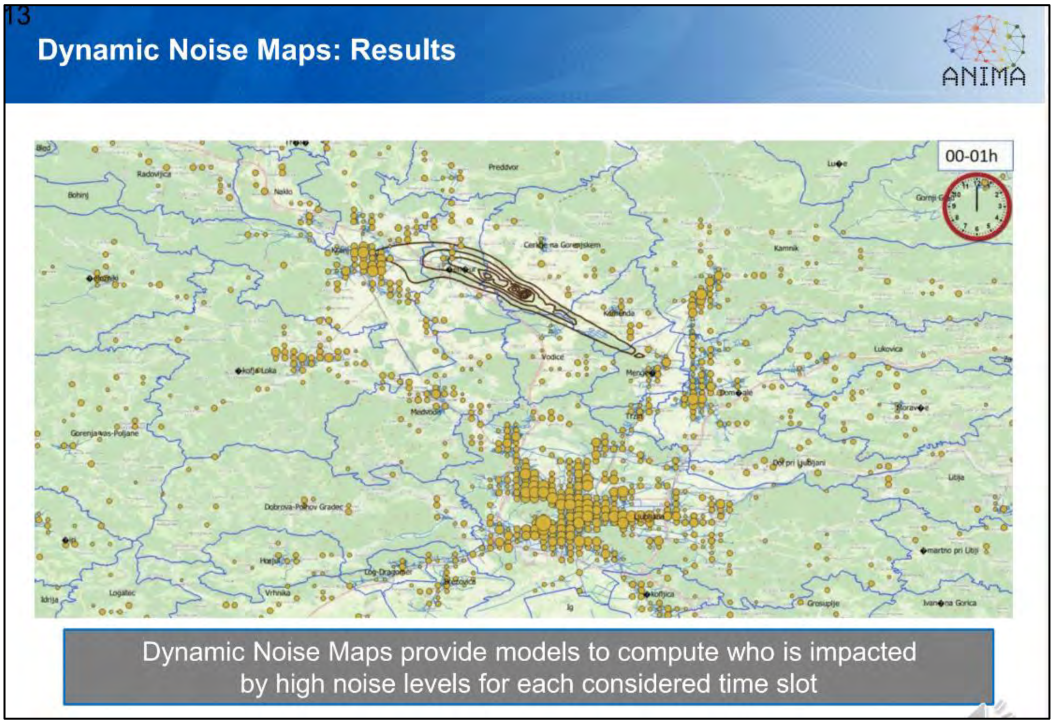


Figure 7.2- 3 *Dynamic noise maps: Yellow dots in this example mark the locations of the population at a given time*

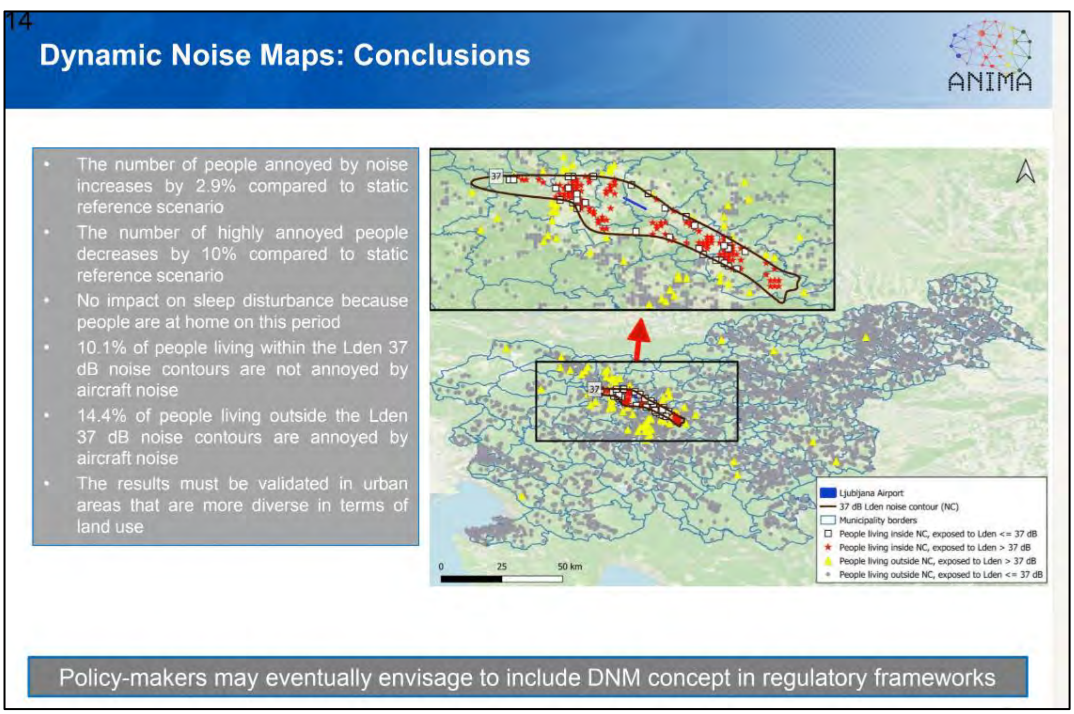


Figure 7.2- 4 *Example shows more people "annoyed" and less "highly annoyed" based on dynamic noise maps compared to static noise maps*

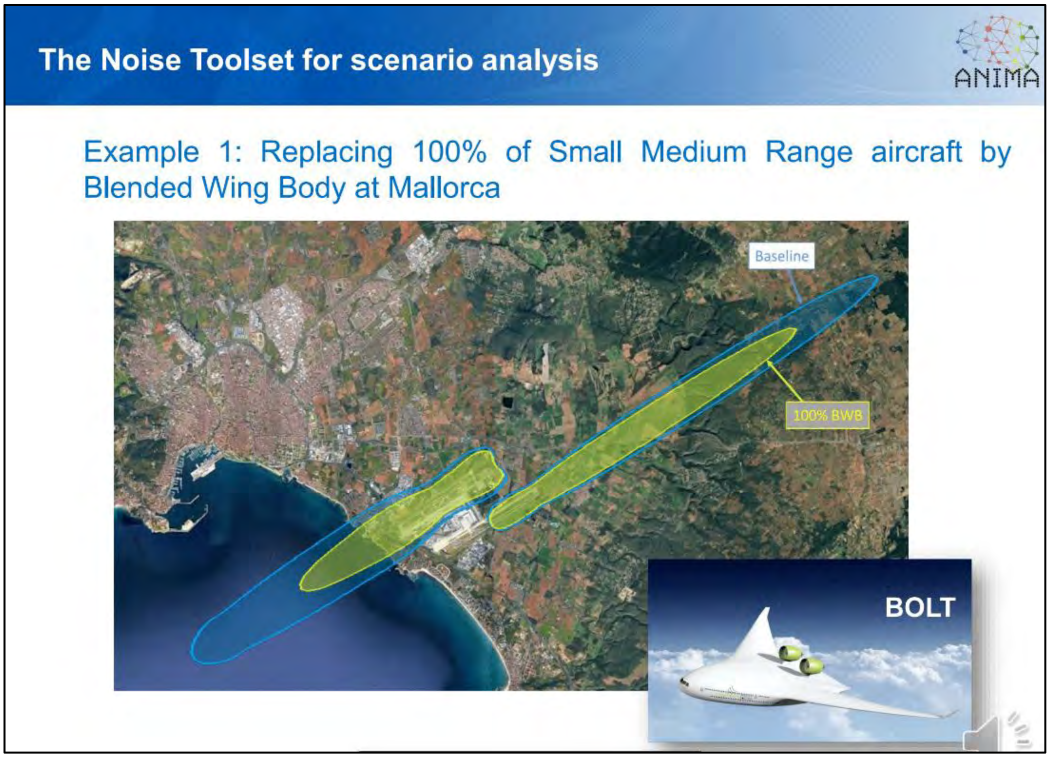


Figure 7.2- 5 *Noise contours shrank when blended wing body aircraft replaced traditional small medium-range aircraft*

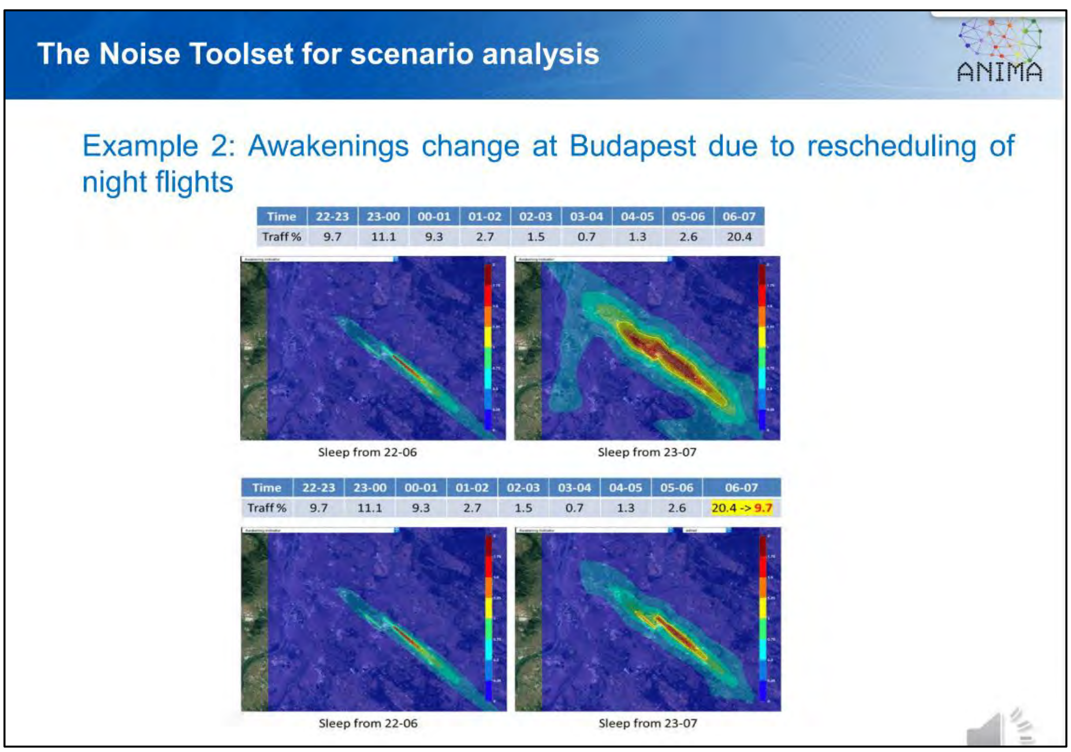


Figure 7.2- 6 *Simulation shows changes in numbers awakened with a shift in overnight flight hours*

7.3 Working With Communities Around Airports When Planning for Changes

Charlotte Clark—St. George's University of London

When contemplating changes around airports that can affect community noise exposure, decision-making amounts to a sensitive balancing act that can involve complex concepts such as "noise envelopes" and an array of policy documents and metrics. When planning for such airport changes, communities are important stakeholders whose input should be thoughtfully considered.

Charlotte Clark, an expert in the field of environmental noise effects on health, and professor of epidemiology at St. George's University of London, shared her expertise about working with local communities when planning for changes at airports. Clark has led research projects examining the effects of aviation noise on children's learning; mental health and well-being; quality of life; cardiometabolic outcomes; and, in a more preliminary way, sleep. She has also participated on a number of expert panels in the UK dealing specifically with the effects of aviation noise on health and quality of life.

The following are among the primary concerns when it comes to changes associated with aviation planning:

- *Design changes on the ground.* An example is the plan to build a new northwest runway at London's Heathrow Airport, which involved extensive planning with considerations including, but reaching far beyond, noise. A master plan overview is shown in Figure 7.3-1 (expansion documents available at www.heathrow.com/company/about-heathrow/expansion/documents).
- *Airspace change.* A key issue is how to distribute noise: Will the noise be more dispersed or will it be concentrated so that fewer people are affected but those impacted are exposed to more noise?

Aviation noise is a "very complex policy landscape." Figure 7.3-2 presents a few of the policy documents relevant to the Heathrow expansion. A process for cost-effectiveness consideration called WebTAG supports assessments of aviation's impacts and allows a comparison among various airspace modification alternatives.

Community issues include important concerns surrounding airspace modernization, and performance-based navigation (PBN), in particular. By concentrating noise over a narrower corridor, PBN raises the delicate issue of whether to newly expose people to noise who are not exposed already, or expose a smaller group of people to more concentrated noise than they already experience.

Mistrust often exists between the community and airport operators, and there is mistrust of the information provided to communities regarding airport changes. "Communities grow quite tired of metrics, metrics, metrics. They feel unheard and unable to influence decisions about airport changes, and they have major concerns about the impacts of noise on their health and quality of life." And communities are weary of the rhetoric about quieter planes and technological solutions, feeling that they have been promised quieter planes for a long time and the issue of noise has not been solved. In fact, some have seen an increase in the number of flights within their communities that can dampen the impact of any gains from quieter planes.

The UK Civil Aviation Authority publication CAP1129 *Noise Envelopes* addresses the concept that benefits of quieter aircraft technology should be shared between industry and local community stakeholders. This is accomplished based on "noise envelope" concepts defined in terms of the measurable parameters of inputs, noise exposures, and noise impacts. Full agreement is required among all stakeholders on the criteria, limit values, and means of implementation and enforcement. While this objective of full agreement may seem unrealistic, the key point is that communities are important stakeholders as rules of engagement are decided upon, and airports wanting to increase their capacity must engage with these stakeholders.

Clearly, noise can affect health, and over the past two decades this understanding has resulted in noise policy that increasingly addresses health effects. Noise's influences on biology through annoyance, and sleep disturbance from nighttime noise, biological responses, and cardiometabolic consequences, are summarized in Figure 7.3-3.

The European Environment Agency, which has set a health effects threshold level of 55 dB Lden, found that 4 million people in Europe are exposed to a level above this threshold from air travel—far less than from road and rail traffic—and that those who are exposed from any of these sources have increased occurrence of premature death and ischemic heart disease, as well as chronic sleep disturbance and high annoyance. Figure 7.3-4 provides some detail in terms of exposure and effects.

Annoyance is a key policy driver in the field of aviation noise. As seen in the Figure 7.3-5 graph, from the World Health Organization systematic review that informed the organization's 2018 noise guidelines for the European region, aircraft noise exposure leads to an increase in being "highly annoyed" as the black line reflects. The red line tracks the older, EU 2002 exposure response function, suggesting that aircraft noise annoyance was higher later.

Exposure response curves are available for a range of outcomes. For example, children attending noisy schools showed poorer learning than other children, as shown in Figure 7.3-6 depicting results of a study conducted by Clark and colleagues. As aircraft noise increases, children's reading comprehension scores decrease. Also, a recent publication on sleep, which updated WHO's systematic review, showed that a 10-dB increase in aircraft noise exposure results in a significant increase in day-later reported sleep quality. This was also the case when survey recipients were only asked about sleep quality and not specifically about noise.

England is fortunate to have a noise policy statement that specifically directs that adverse impacts on health and quality of life should be avoided, where possible, with the goal of mitigating and minimizing these adverse impacts toward improving health and quality of life. A toxicological approach sets so-called LOAEL (lowest observed adverse effect level) and SOAEL (significant observed adverse effect level) values, which vary depending on the airport. The LOAEL is a threshold level above which adverse effects on health and quality of life can be detected, and the SOAEL represents a level above which significant adverse effects on health and quality of life occur. It can be difficult to identify thresholds where effects and significant effects begin, and effects of noise on health have been shown over the past 10 years to begin at a much lower level than previously thought.

While England's noise policy statement directs attempts to determine where health effects begin, using LOAEL- and SOAEL-based assessments, WebTAG contributes a cost-benefit appraisal that monetizes these noise effects on health. Together, this information helps determine mitigation/minimization efforts to comply with restrictions under the policy.

Figure 7.3-7 shows a large area of London and the Heathrow expansion's third runway. The LOAEL value, shown in blue, was set by policy at 51 dB on the 16-hour equivalent continuous sound pressure level (LAeq). The SOAEL is shown in purple, while yet another key level, the unacceptable adverse effect level (UAEL) is marked in red. More detailed information can be found online, including population numbers relevant to the assessment.

Communities have their own views regarding LOAEL, and some may advocate for the use of the WHO environmental noise guidelines for the European Region, including WHO's 45 dB LDEN level as the threshold for adverse health effects from noise. This value was set at the level at which 10 percent of the population were highly annoyed. A recent UK noise attitude survey, however, suggested that 10 percent of the population would actually be highly annoyed at about 54 dB on a 16-hour equivalent basis. It is argued, then, that the 51 dB level under the England policy is underestimating noise effects because it is higher than the WHO standards.

With research partners, Clark is studying fair and equitable distribution of aircraft at Gatwick Airport. (Torija, Clark, Lavia, Manuel & Lomax. 2022. *Study on fair and equitable distribution of aircraft at Gatwick*. Technical Report, University of Salford http://usir.salford.ac.uk/id/eprint/63313/). Communities have been taught about, and understand, relevant metrics. While health studies tend to use certain exposure metrics such as N60 (daytime) and N65 (nighttime) and LAeq (day) and LAeq (night), communities do not feel the traditional metrics represent their experiences. Their preferred metrics would capture their experiences and exposure during certain times of the day, for example. Communities tend to prefer analyses based on LAmax, LAeq,T (LAeq measured over a shorter time T), overflights, and psychoacoustic measures such as loudness.

Figure 7.3-8 summarizes outcomes from the study by Clark's team. The group's framework for fair and equitable distribution included a host of personal-, location-, context-, and community-level non-acoustic factors. The framework's acoustic metrics included health and operational metrics that could help airports collaborate in detail with communities. Further stages in the process would focus on performance indicators, incentives, objectives, and outcomes review.

Engaging with communities can be confrontational at times, but difficult conversations can lead to a better understanding of differing viewpoints. "I think we can increasingly expect pushback from communities on the grounds that there are health effects of aviation noise, and based on the WHO guidance. It is important to appreciate communities despite some disagreement, and respect that what is good for one community might not be good for another." Communities may place increasing pressure for change in this area. Issues involved are complex, and when balancing community benefits and disbenefits, issues of effectiveness and fairness should remain front of mind and solutions must be created collaboratively.

During the post-presentation period for questions and comments, a participant echoed the importance of engaging with the community on aviation noise decisions, and commented that the WHO recommendation is unrealistically low, given that 45 dB is the level of noise in a quiet room. Clarke commented that the levels are "very challenging" and have received criticism regarding a lack of economic analysis about the meaning for real-world airport operations. Perhaps the intention was to motivate people to strive for much lower noise levels, but the super-low levels may have caused people to give up on even seriously considering steps in the right direction.

Another workshop participant asked whether any studies have been undertaken to show whether, and to what extent, engagement with communities actually improves their acceptance of airport noise. Clark responded that, while such quantitative data is lacking for aviation noise, studies of railway noise found that communication with those affected is associated with reduced annoyance. An attempt is being made to encourage studies in the UK to shed light on this question in the aviation sphere, but it is unclear that everyone even wants an answer.

An attendee commented that, in the Netherlands and around Schiphol Airport outside Amsterdam, in particular, noise has polarized groups. He referred attendees to a small study in this area discussed in the book, *Aviation Noise Impact Management: Technologies, Regulations, and Societal Well-being in Europe*, available online at https://link.springer.com/content/pdf/10.1007/978-3-030-91194-2.pdf. The study found that communication between airports and communities can at least help identify the most important issues to address; that flyovers deviating from the expected departure routes were met with increased annoyance; and that metrics such as yearly LDEN noise levels should be understood by communities and distinguished from other values such as peak noise levels.

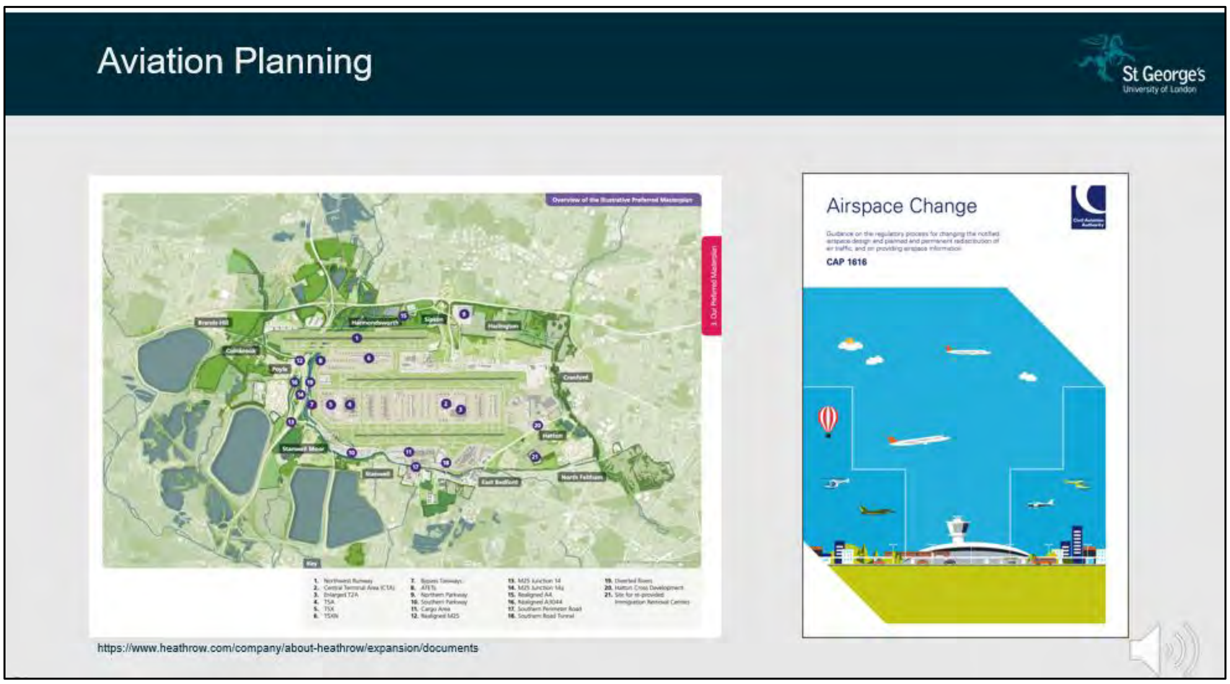


Figure 7.3-1 *Heathrow expansion planning*

Figure 7.3-2 *Various policy documents influence decisions*

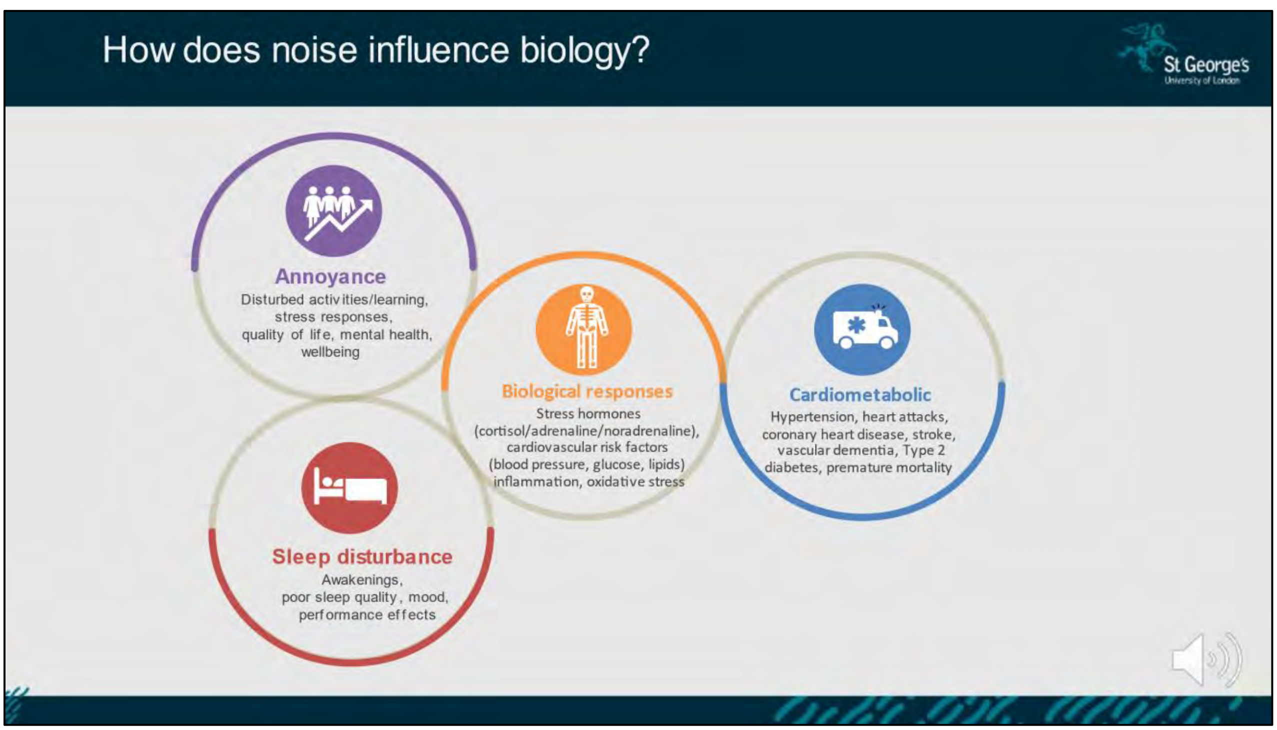


Figure 7.3-3 *Noise affects health and well-being*

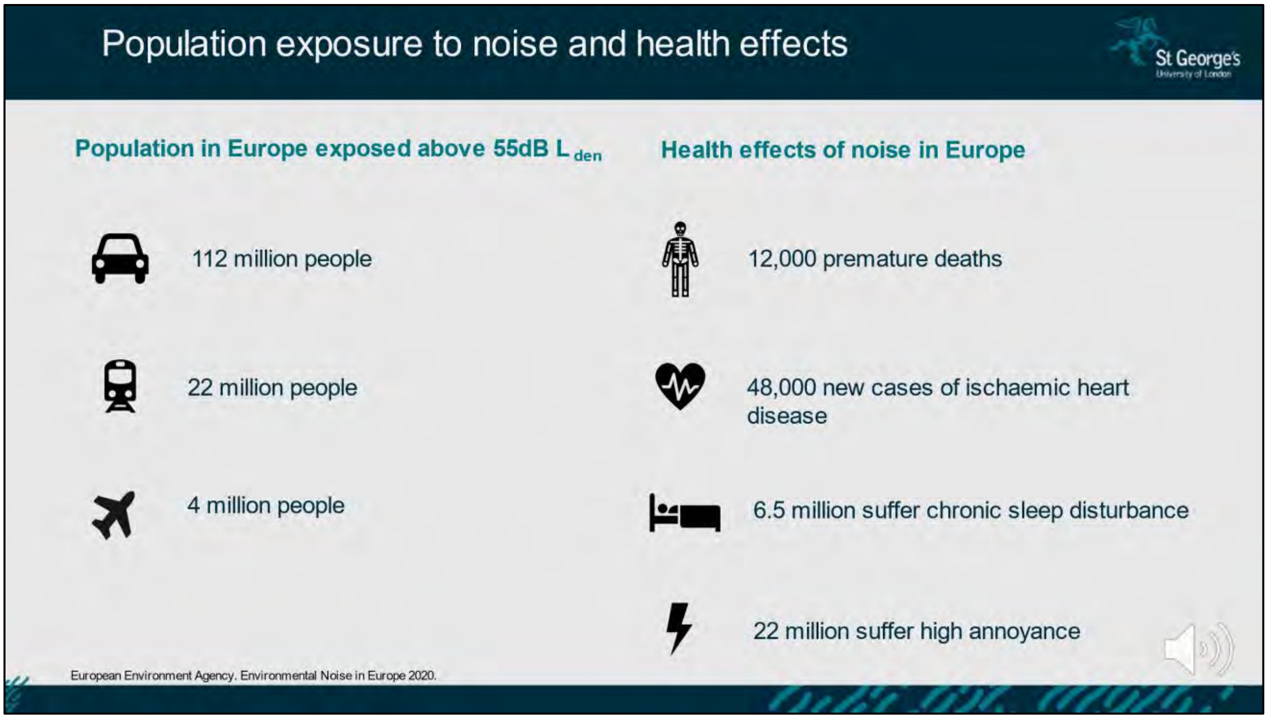


Figure 7.3-4 *Noise exposure and health effects: European Environment Agency findings*

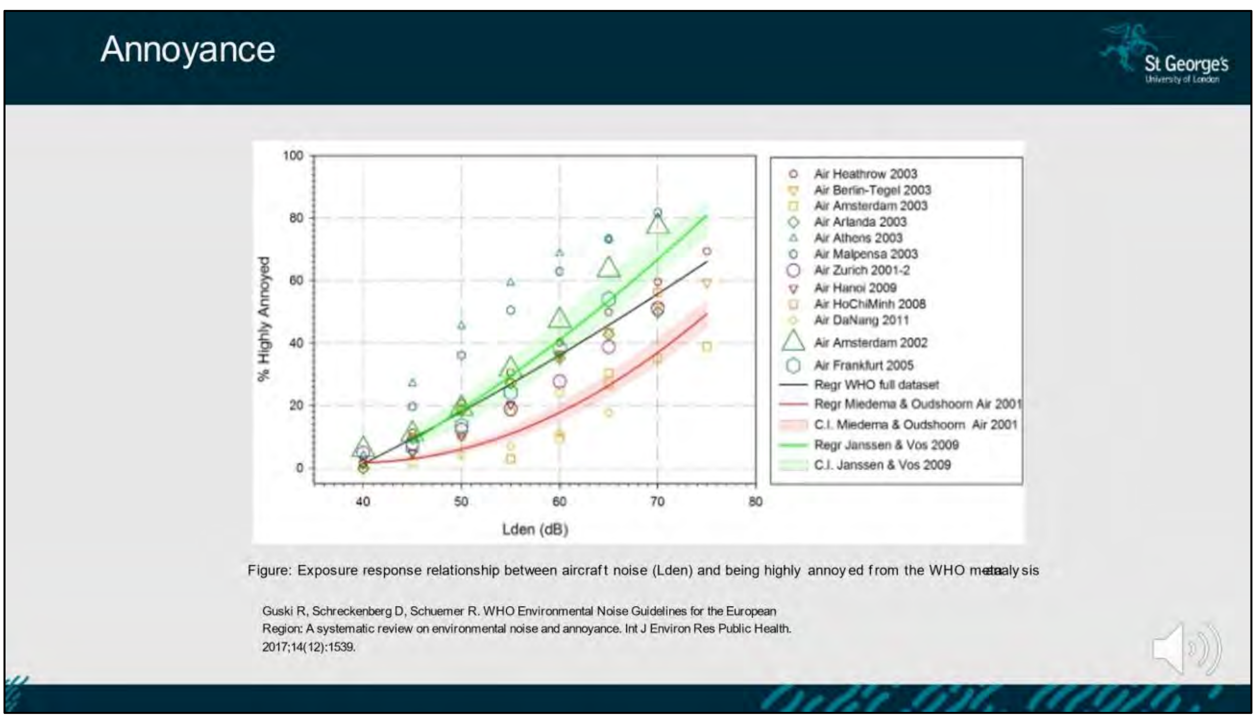


Figure 7.3-5 *Association of annoyance with aviation noise exposure: WHO findings*

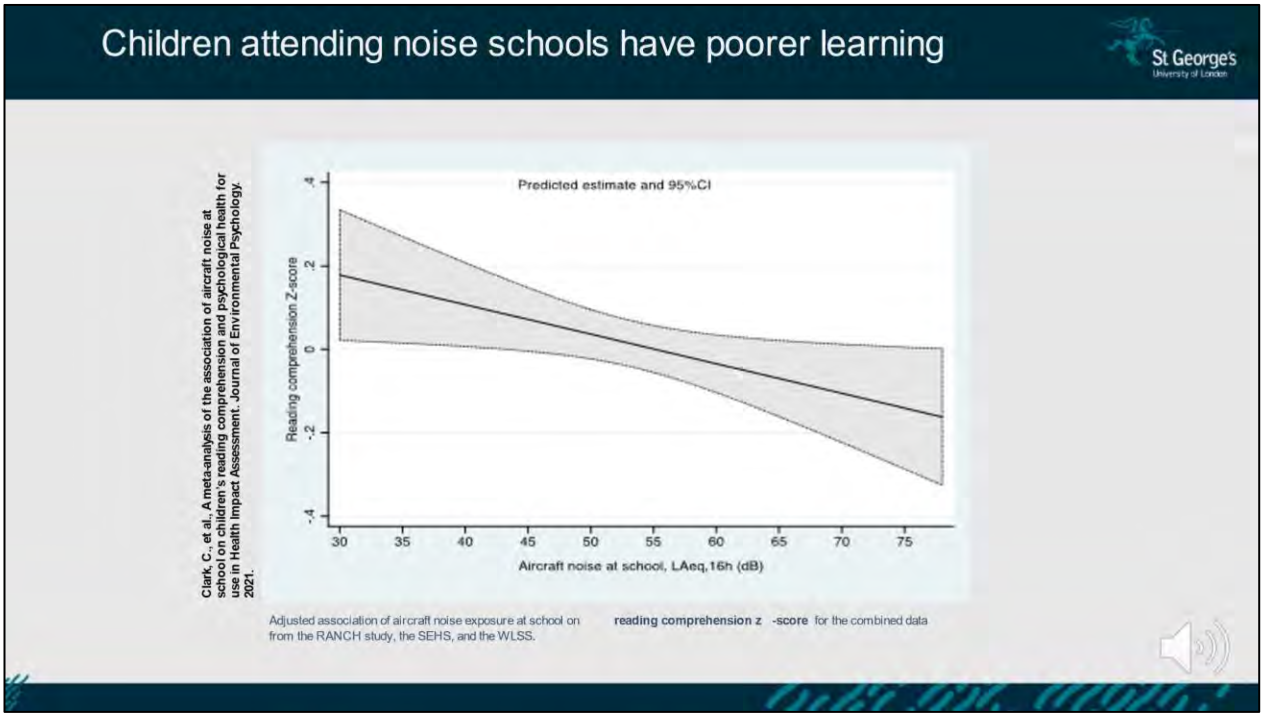


Figure 7.3-6 *Noisy schools are associated with poorer learning*

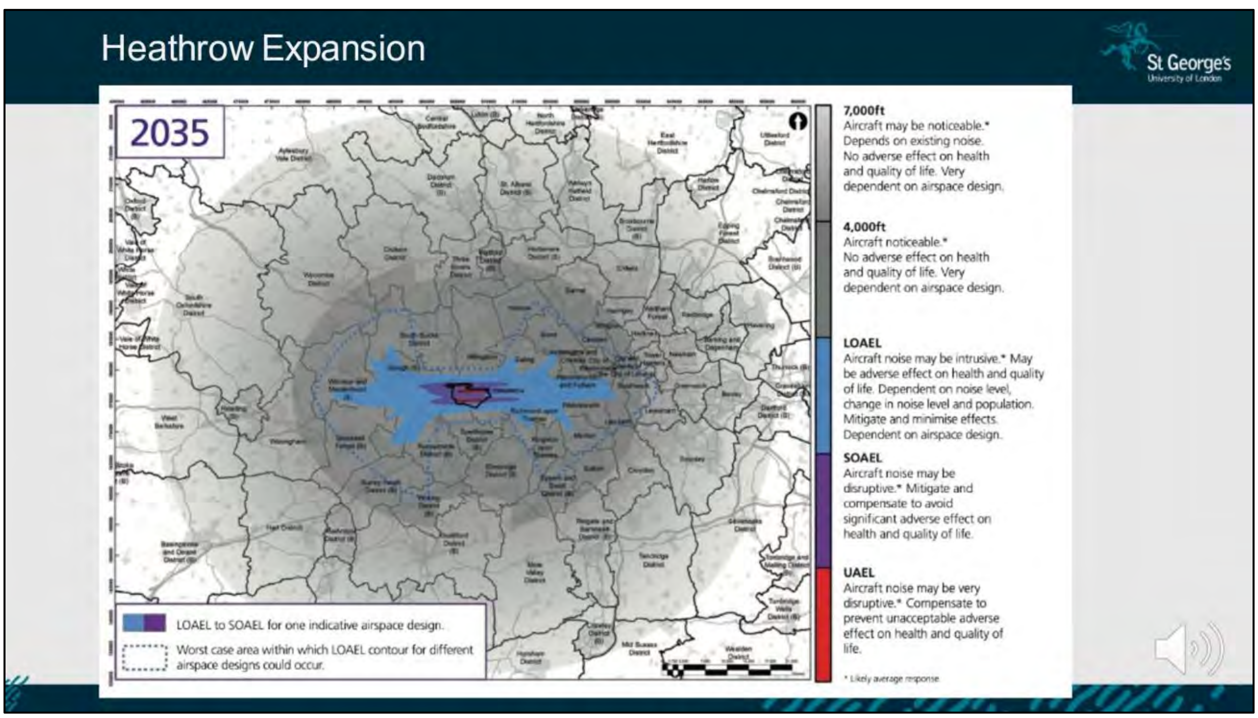


Figure 7.3-7 *Noise levels under Heathrow expansion*

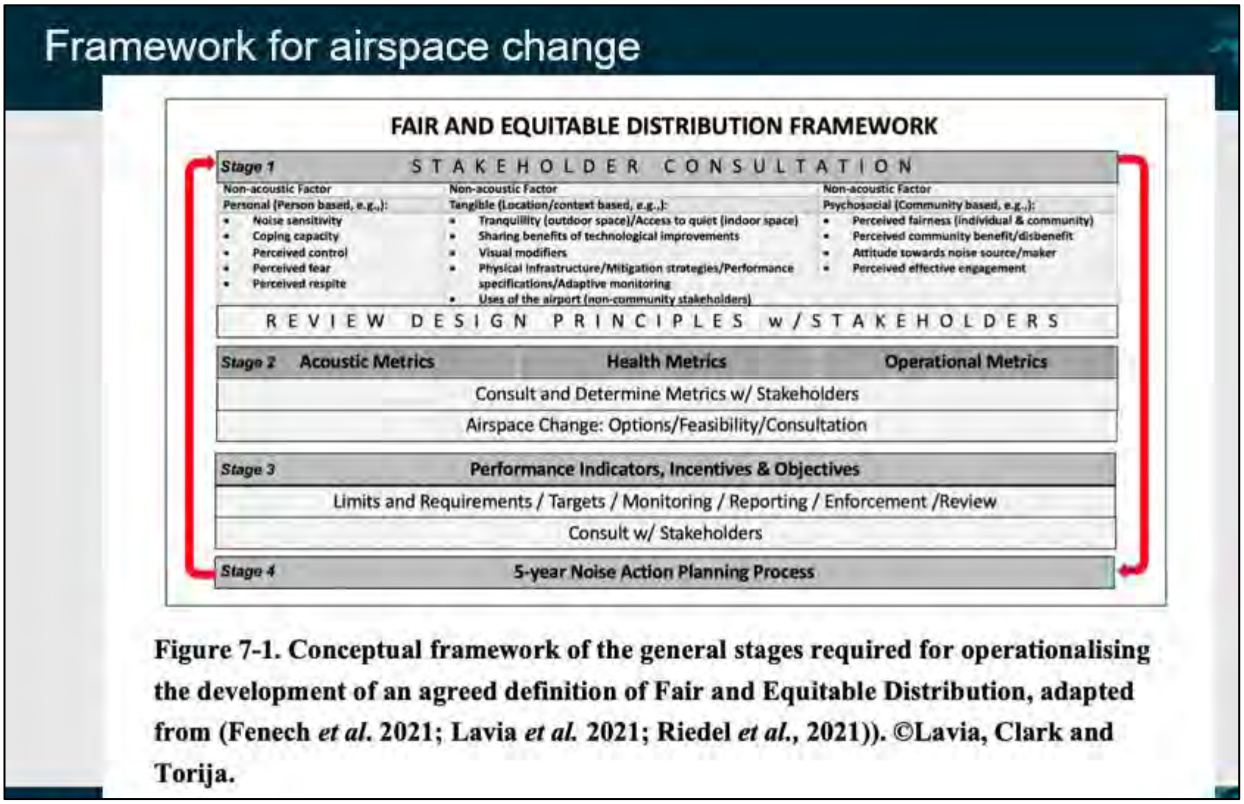


***Figure** 7.3-8 Framework for fair and equitable noise distribution*

7.4 Issues Affecting Results of Noise Surveys Around Airports

Truls Gjestland—SINTEF Digital, Norway

To understand, apply, and meaningfully compare results from noise and annoyance surveys around airports, careful attention must be paid to how the surveys have been conducted—via phone or mail, for example. For useful comparisons, surveys must have been conducted using the same methods, or alternatively, adjustments must be made in analysis. Given open questions in these regards, the World Health Organization definition of acceptable noise exposure levels is too vague for use in regulatory standard-setting.

Truls Gjestland, with independent research organization SINTEF, discussed factors affecting the results of noise and annoyance surveys around airports. Results from such surveys are heavily dependent on how the appraisals are conducted.

Results from noise annoyance surveys are traditionally presented as dose-response curves, or exposure-response curves, showing the prevalence of annoyance as a function of the accumulated noise exposure level at DNL or DENL. This concept, as represented in Figure 7.4-1, was introduced in 1978 by Ted Schultz, who adopted as a basic rule that people whose responses were in the upper 27–29 percent of a numeric annoyance scale should be considered "highly annoyed." Stated another way, Schultz used a cutoff of 71–73 percent in this context.

The U.S. Federal Interagency Committee on Noise (FICON) declared that the percentage of the area population characterized as "highly annoyed" by long-term exposure to noise was its preferred measure of annoyance. And according to WHO, noise corresponding to 10 percent "highly annoyed" is the limit for acceptable exposure, and noise above this level "is associated with adverse health effects."

International technical specification ISO/TS 15666 describes how social surveys on noise annoyance should be conducted, but says little about the concept of "highly annoyed" and how its prevalence should be determined. The presentation focused on different factors that affect the response in a noise survey and consequently affect the determination of the critical quantity "percentage highly annoyed."

To compare responses from different surveys, results must be quantified in a meaningful and unambiguous way. The community tolerance level (CTL) method for assessing noise annoyance is an "ideal" tool for this purpose. It contrasts with the traditional way of establishing an exposure-response curve based on survey results, which divides respondents in exposure bins—for example, 5 dB bins—and then plots the response per bin. That is, pairs of exposure level and prevalence of high annoyance are determined, as in the example in Figure 7.4-2. Then, conventional regression analysis is used to find a curve with the best fit for the dataset, leaving both slope and intersect to be determined.

The CTL method is based on a different approach that assumes annoyance increases with noise level, as does loudness, and therefore the shape of exposure response curves is fixed regardless of survey results. The position of the CTL function relative to the x-axis will vary based on non-acoustic factors. The curve is anchored by convention to the x-axis, to the noise level at which half the population is highly annoyed. In Figure 7.4-3, 50 percent is the community tolerance level, meaning half the population is highly annoyed and the other half is not highly annoyed.

SINTEF

A high CTL value characterizes a community with a high tolerance for noise and thus low annoyance prevalence. A low CTL value indicates the opposite. Differences in the CTL value between two surveys indicates how much the noise level in one situation must be increased or decreased, compared to the other situation, to produce the same degree of annoyance. In the example shown in Figure 7.4-4, the difference in CTL values in the two situations shows the shift in noise level necessary to equalize the two.

The ISO 1996 standard describes the CTL method as “estimated prevalence of a population highly annoyed as a function of adjusted day-evening-night or day-night sound levels using the community tolerance level formulation.” The method is also standardized under ANSI/ASA S12.9.

Results from previous noise annoyance surveys have been systematically analyzed using the CTL method. A database compiled by James Fields comprising more than 1300 original reports and journal articles on noise annoyance surveys conducted prior to 2008 helped invaluably. Results from surveys conducted after 2008 have been found in major acoustic journals and proceedings from international conferences. The Socio-Acoustic Survey Data Archive (SASDA) established by the Institute of Noise Control Engineering, Japan, also provided valuable data.

The annoyance response is usually affected by a set of non-acoustic factors, and it may be difficult or impossible to isolate the effects of individual factors. “The results presented in this study should therefore be considered as examples or qualitative trends, and not necessarily as descriptive of effects in absolute quantitative terms.”

What would the effect of the response scales be? The ISO technical specification for conducting noise annoyance surveys recommends the usual two response scales: a 5-point verbal scale and an 11-point numerical scale. Traditionally, people responding to the upper two categories of the verbal scale or the upper three categories of the numerical scale are considered highly annoyed.

Gjestland and Morinaga (2022) analyzed 43 surveys where annoyance has been assessed using both the verbal and numerical scales, and the average difference in CTL value was 6 dB. Surveys conducted 40 or 50 years ago tended to be conducted with face-to-face interviews in the respondents’ homes, whereas today telephone interviews seem to be the favored method. Due to low response rates by phone, surveys are sometimes conducted by direct mail, as well as via open online surveys. And emerging methods such as computer “clickers” can be used for surveys, as well.

Fidell et al. (2022) examined several survey methods, finding no significant difference between telephone and face-to-face interviews. Self-administered postal interviews, on the other hand, seem to yield different results. The average CTL value for 10 postal surveys conducted between 1993 and 2016 was 63.3 dB, whereas similar analysis of 35 face-to-face or telephone surveys showed a CTL of 73.3 dB—a 10 dB difference compared with postal surveys.

Miller et al. (2021) conducted a 20-airport study in the United States, using the same surveys by telephone and by mail in the same communities. The researchers found a significant difference of about 5 dB between the two methods, with people responding to the postal survey seeming to tolerate 5 to 10 dB less noise to express the same degree of annoyance versus respondents in the live-agent phone survey.

When transportation traffic volume increases, so does noise level, and consequently annoyance also increases, with annoyance seemingly increasing at a faster rate than the equivalent level. Gjestland et al. (2017) studied the prevalence of noise-induced annoyance and its dependence on the number of aircraft movements. From their analysis of the results of 32 aircraft noise surveys, the team concluded that the percentage of highly annoyed residents increased equivalently to a DNL increase of 1.8 per doubling of the number of aircraft movements. To express the same level of annoyance, residents living near a small airport seemed to tolerate about 6 dB more noise than those living near an airport with 10 times the traffic.

Most airports experience an increase in traffic gradually over years of operation, with the small incremental increases in noise exposure hardly noticed by community residents. Occasionally, however, abrupt changes occur—for example, with the introduction of a new runway, a new fleet of aircraft when an airport moves its hub, or new operational procedures or flight trajectories.

Janssen and Guski studied temporal trends in the aircraft noise annoyance response by analyzing 32 aircraft noise studies contained in the TNO database. The researchers observed that an abrupt change in airport operations affected annoyance response, and they introduced a classification procedure that differentiated "low-rate change" airports from "high-rate change" airports.

In another analysis, Gelderblom et al. (2017) studied the stability of community tolerance to noise based on 62 aircraft noise annoyance surveys. Using the Janssen and Guski definitional classifications, the researchers found that people living near a high-rate change airport seemed to tolerate 9 dB less noise to express the same degree of annoyance compared to residents living around a low-rate change airport.

Analysis shows that prevalence of highly annoyed residents around an airport depends on a number of factors other than the accumulated equivalent level. These factors must be considered when comparing response in different communities and when assessing a noise situation with respect to existing environmental noise regulation. These non-acoustic factors are summarized in Table 7.4-1.

Different factors are working independently of each other, and shifts in CTL value may therefore be considered additive to some extent. For example, the effects of survey modes and of response scales are likely to act independently.

In the example of the Miller et al. study of 20 airports conducted for the FAA, the researchers concluded that the national average dose-response curve showed a much greater prevalence of high annoyance compared to the current ISO reference curve. As seen in the dose-response curve in Figure 7.4-5, based on use of a 5-point verbal scale, the community tolerance level was found to be L_{CT} 60.2 dB.

To compare the FAA 20-airport study with the current ISO reference curve, however, adjustments are needed for differences between verbal and numerical response scales and postal and telephone survey modes. As summarized in Figure 7.4-6, required total adjustment amounts to 11 to 16 dB. The adjusted result is a level of 71.2 to 76.2 dB, which according to Fidell's analysis of the ISO reference curve, closely resembles a CTL function with an anchor point of 73.3 dB. The comparison results in an almost perfect fit, as reflected in Figure 7.4-7, with the 20-airport study yielding almost exactly the same results as the ISO reference— "a very different assumption than the alarming conclusion by Miller et al."

While WHO considers an exposure level associated with 10 percent highly annoyed to be the limit for acceptable noise exposure, the organization does not speak to how the prevalence should be determined. The 10 percent figure is therefore a very imprecise quantity, given that CTL results from a survey on annoyance from aircraft noise can easily differ by as much as 10 dB, based on how surveys are conducted.

An overarching takeaway from this presentation is that survey results can be meaningfully compared only if the surveys have been conducted in the same way or if the results have been appropriately adjusted. The WHO definition of acceptable safe exposure is therefore ambiguous and not suitable for setting limits for regulatory purposes.

Steps are being taken to support appropriate comparisons from different survey approaches. For one, a recent revision of ISO/TS 15666 recommends a way to convert verbal responses to numerical responses toward making scales comparable. A journal article that may be instructive in this area is “Pooling and Comparing Noise Annoyance Scores and ‘High Annoyance’ (HA) Responses on the 5-Point and 11-Point Scales: Principles and Practical Advice” by Brink et al. (2021).

Table 7.4-1 *Adjustments to CTL for non-acoustic factors*

Effect	Non-Acoustic factors	Adjustment ΔL_{CT}, dB
Response scale	Verbal - Numerical	6
Survey method	Postal - Telephone	5-10
Traffic volume	2 x movements	1.8
	10 x movements	6
Operational changes	Abrupt changes vs no changes	9

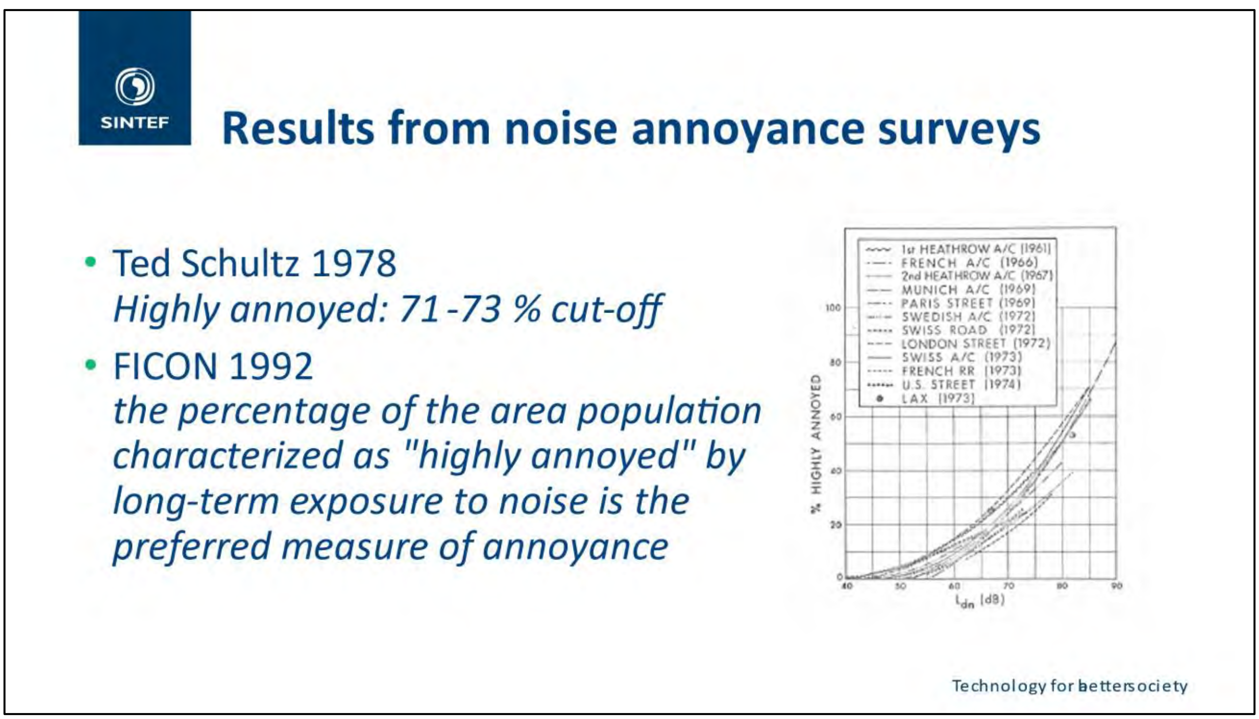


Figure 7.4-1 *Results from noise annoyance surveys*

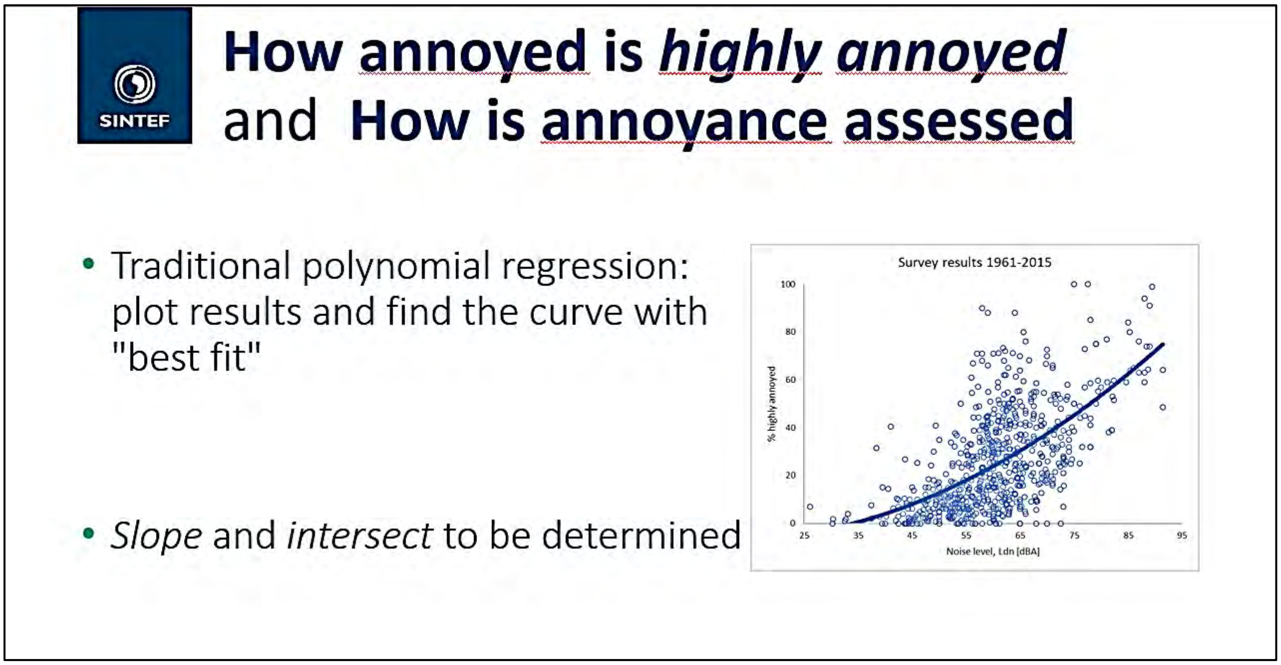


Figure 7.4-2 *How annoyed is highly annoyed and how is annoyance assessed?*

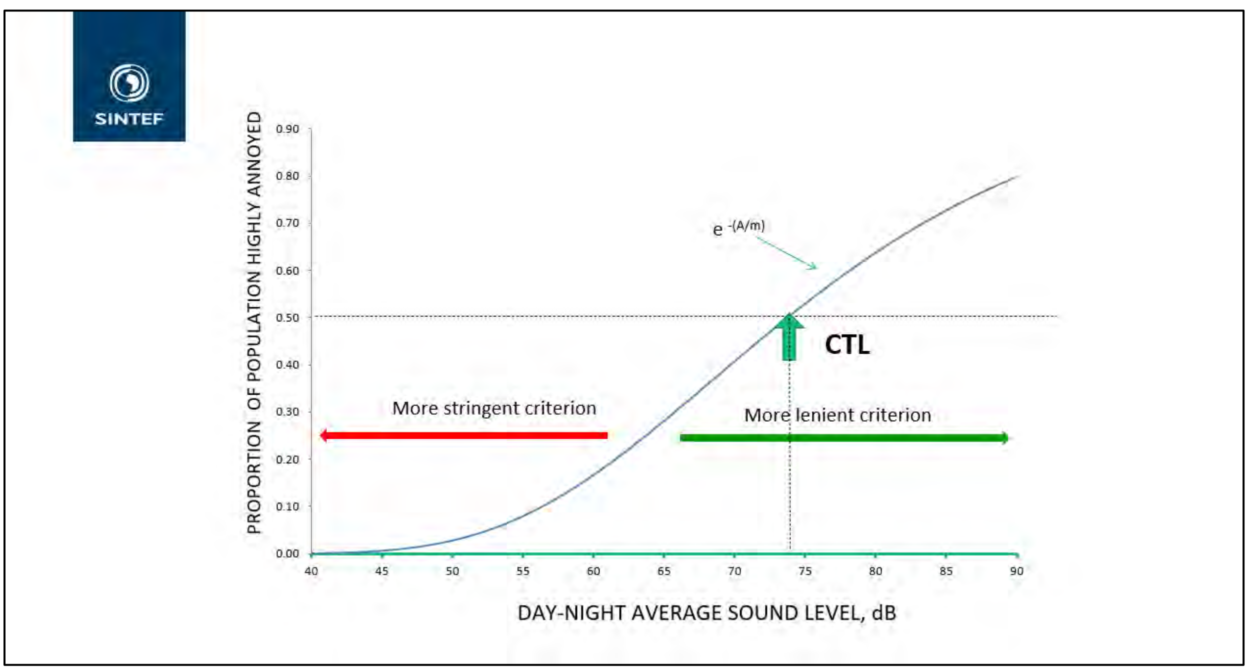


Figure 7.4-3 *CTL is 50 percent, meaning half the population is highly annoyed*

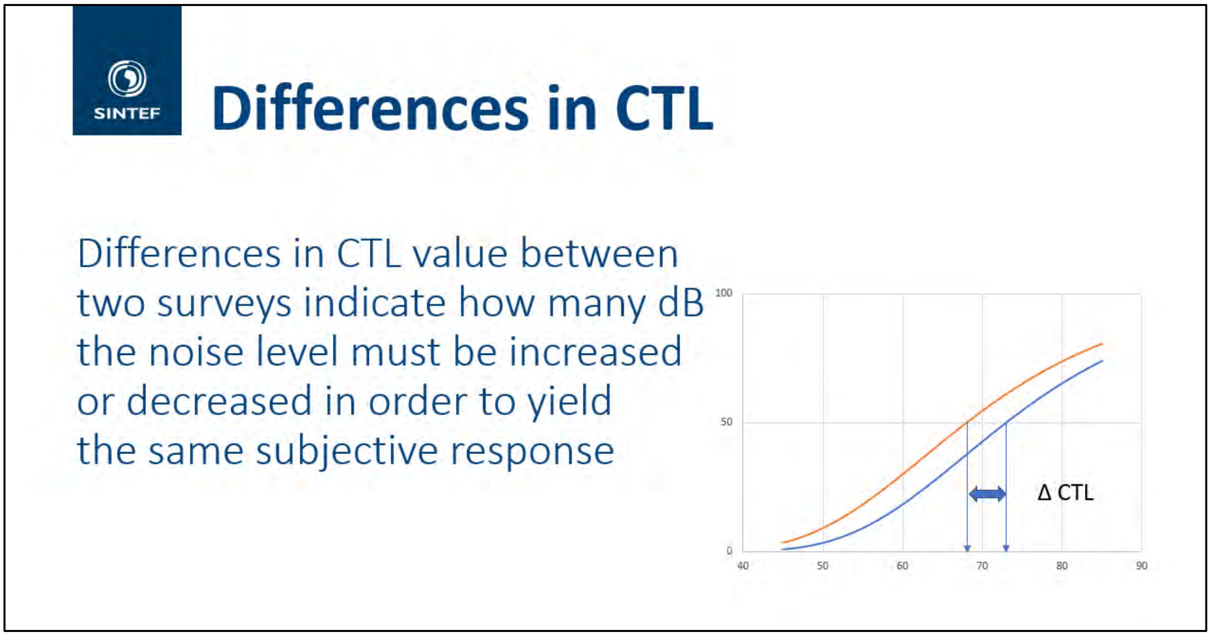


Figure 7.4-4 *Two surveys' CTL values indicate noise level shift needed to equalize subjective responses*

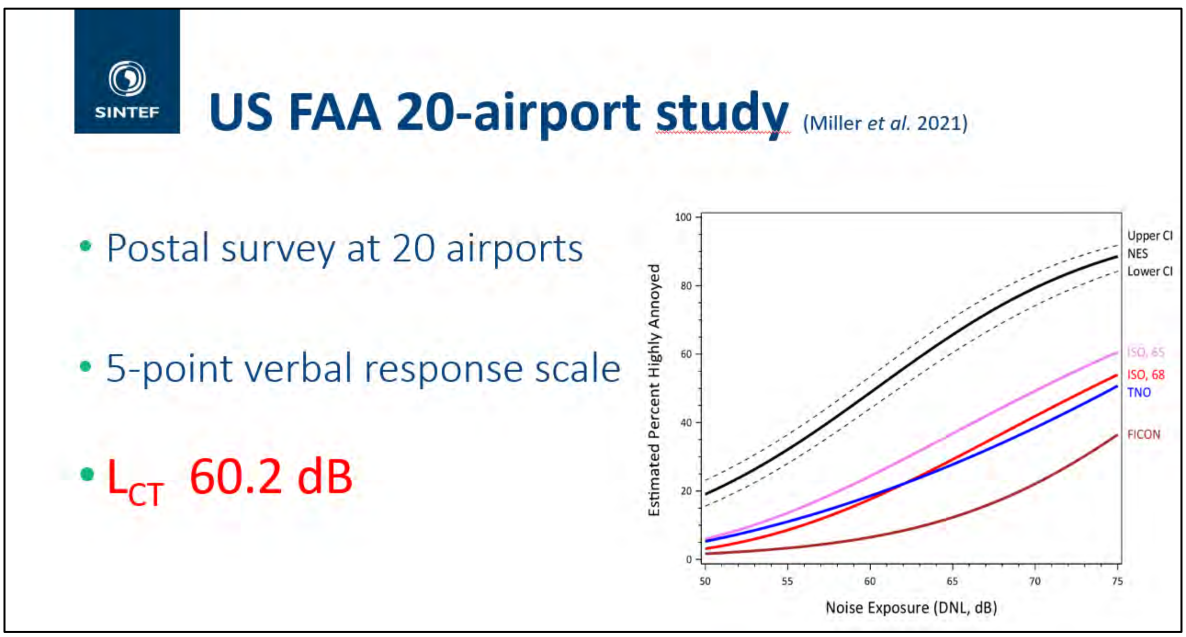


Figure 7.4-5 *US FAA 20-airport. dose-response curve*

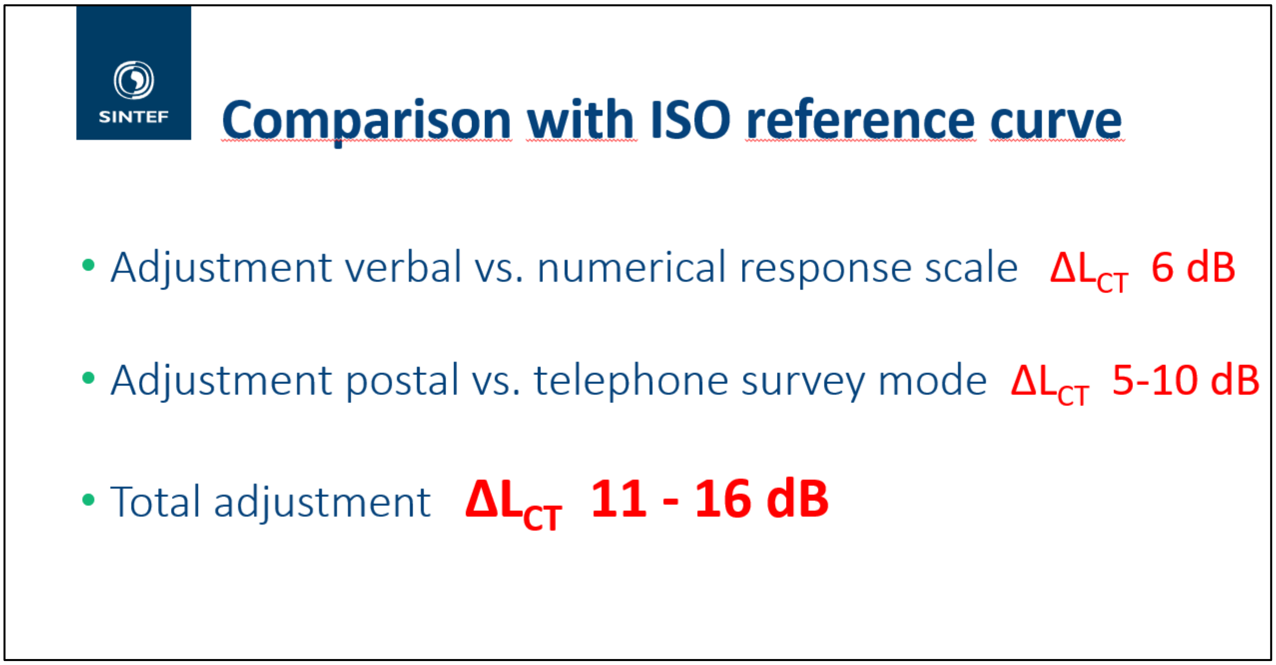


Figure 7.4-6 *Adjustments required to compare the FAA 20-airport study with the ISO reference*

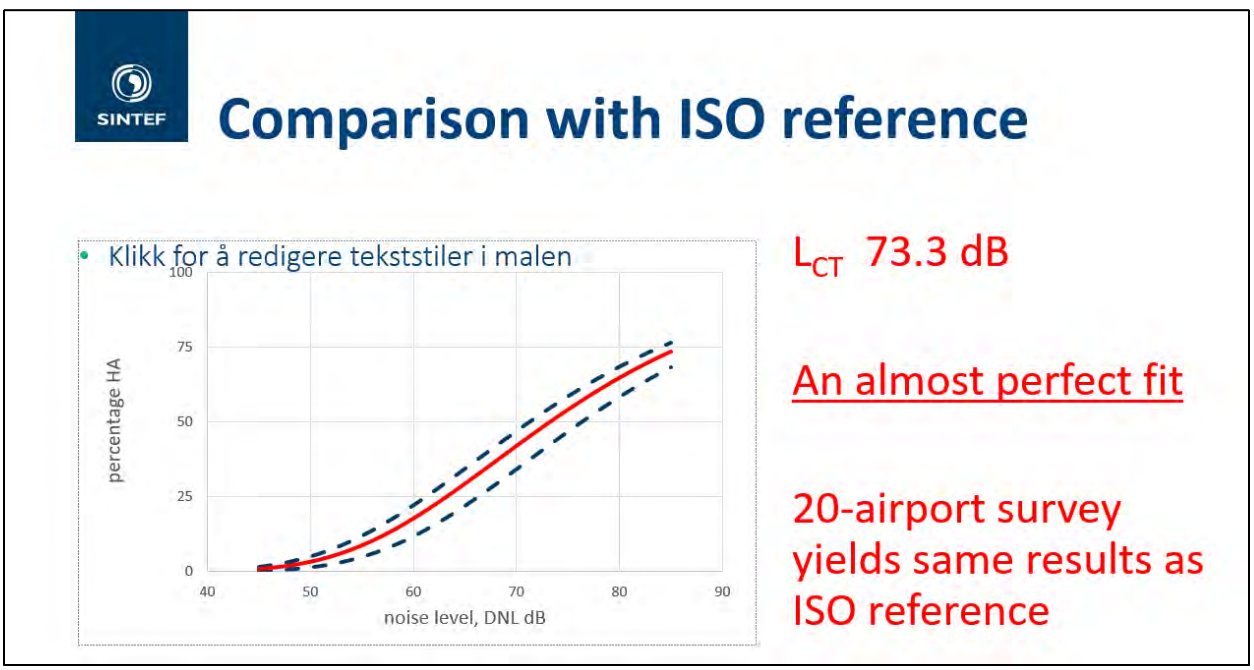


Figure 7.4-7 *"Almost perfect fit" seen between results of FAA 20-airport survey and ISO reference*

7.5 Updates on the FAA and Its Neighborhood Environmental Survey

Adam Scholten and Donald Scata— US Federal Aviation Administration (FAA)

The FAA's Neighborhood Environmental Survey (NES), a nationwide survey that examined annoyance related to aircraft noise, created a revised national dose-response curve for the day-night average sound level (DNL). The survey showed the usefulness of DNL as a metric for quantifying annoyance in the context of airport noise, while recommending the exploration of other measures that could improve quantification of the experience of communities near airports. The NES, along with follow-on analysis, will help to inform the FAA's future noise policy decisions.

Adam Scholten, an environmental protection specialist within the Noise Division of the FAA's Office of Environment and Energy, spoke on behalf of himself and the FAA's Donald Scata, manager of the Noise Division, about the results of the FAA's Neighborhood Environmental Survey (NES) and related research to help inform future U.S. aviation policy.

The nationwide NES, which involved 20 representative U.S. airports, measured the relationship between aircraft noise exposure and annoyance experienced by communities near the airports. The goal of the NES was to better represent the experience of these communities, given the perceived shortcomings of the Schultz curve and dose-response data based on the day-night average sound level (DNL) in reflecting public perception of U.S. aviation noise. Full NES results, which were released in February 2021, can be found at https://www.faa.gov/regulations_policies/policy_guidance/noise/survey along with supplementary information.

The NES supported development of a revised national dose-response curve for DNL that showed that the metric provides a useful measure for quantifying annoyance. Notably, a substantial increase was shown to have occurred since the Schultz curve was developed in the percentage of people highly annoyed by aircraft over the entire range of studied aircraft noise levels.

The NES also found that other noise metrics should be explored for their potential role in improving quantification of community experience and annoyance with aircraft noise. Many communities have expressed that a disconnect exists between DNL and individual lived experiences.

NES data have been used for follow-on analysis related to noise metrics, focusing primarily on the issues of noise metrics, averaging techniques, and weighting. A dose-response curve was created for number-of-events above (NA) a maximum sound level (Lmax) of 55, 60, 65, and 70, with NA55 Lmax and NA60 Lmax curves showing consistent responses in percent highly annoyed when plotted over equivalent ranges to the NES DNL curve. The NA60 Lmax curve tracked best with the DNL curve among the various studied Lmax levels. This analysis "shows that the number above is also a very good predictor of annoyance that is pretty consistent with DNL results."

The plot in Figure 7.5-1 reflects these results, with the y-axis showing percent highly annoyed and the x-axis showing noise levels in DNL. Dose-response curves are also plotted, including the NES and 1992 FICON DNL curves as labeled, along with the various number-above dose-response curves derived from NES data. The shape of the NA60 curve is seen to correlate very well with the NES DNL dose-response curve. The upper x-axis is different than the lower one, showing number of events above a given maximum sound level threshold. Looking at the NA60 curve, for example, following that curve to the intersection with 65.7 percent of individuals highly annoyed gets one to roughly 225 events. And this equates to roughly DNL 65 dB(A) on the lower x-axis.

Another area of NES follow-on research, represented in Figure 7.5-2, is how DNL compares to NA in terms of area exposed to noise. Differences were observed between noise exposure extent using DNL as opposed to NA60 Lmax with different averaging schemes. For example, comparing NA60 Lmax for a maximum contour area day with DNL for the same maximum contour area day, differences in extent of noise exposure are seen.

NES researchers also explored whether any underlying factors could explain airport-to-airport differences observed in DNL dose-response curves generated from the NES. As summarized in Figure 7.5-3, individuals' annoyance was paired with their noise exposure to examine whether and which additional factors may be influencing responses. After controlling for DNL, the research team looked at climate and other factors, finding that only the "noticeable" factor exhibited any ability to explain differences in airport-to-airport dose response curves, and this factor's contribution was "marginal at best."

Comparing the ratio of daily operations to average annual day (AAD) operations for NES airports, the average ratio across all airports was found to be 1. But fluctuation was great among the 20 airports, with some airports found to have a ratio of daily operations that was only 55 percent of AAD and others reaching 145 percent of AAD. This analysis is charted in Figure 7.5-4. Looking at equivalent sound level at different periods of time, analysts compared DNL and NA60 Lmax, looking at various factors such as maximum operations day, maximum area day, maximum extent of all daily DNL contours, maximum operations hour (6 p.m.), maximum area hour (6 a.m.), and maximum extent of all hours. "What we found is not surprising: There is a lot of variation depending on which averaging scheme you use."

In Figure 7.5-5, the upper left image shows DNL. The lower right image looks at hourly equivalent sound levels (Leq), showing both a 24-hour Leq and then maximum operations hour Leq, maximum area hour Leq, the maximum extent of all hourly Leqs, and AAD DNL. Great variation is seen in contour shape and size, based on averaging scheme.

And lastly, as detailed in Figure 7.5-6, the analysts looked at weighting—specifically, in terms of community noise equivalent level (CNEL); morning shoulder hours; and tempo, or percentage change in hourly operations. The CNEL, with weighting applied as described in the figure, increased the size of the contours for DNL 65 dB by approximately 9 percent—"unsurprising" given the additional weighting. A similar result was found with the morning shoulder hour contours, which increased the contour for DNL 65 dB even further, resulting in an 18 percent increase relative to the DNL 65 dB contour from the NES. Lastly, with temporal weighting as described in the figure, strictly based on changes in operations, the area of the contour decreased by 5 percent overall compared to the NES DNL 65 dB contour. However, large fluctuations were seen between airports. This is seen on the plot in Figure 7.5-6, which shows the various weighting schemes and the differences in area from the DNL 65 dB contour.

The results of the NES and follow-on analyses will help to inform the FAA's review of its civil aircraft noise policies. The agency is in the process of reevaluating its primary noise metric—DNL—and the significance threshold of DNL 65 dB. A priority area of focus in the reevaluation is whether DNL should even continue in use as the agency's primary noise metric, and what other metrics should be used. During this policy review, the FAA will extensively engage with its stakeholders including representatives from industry, communities, and airports.

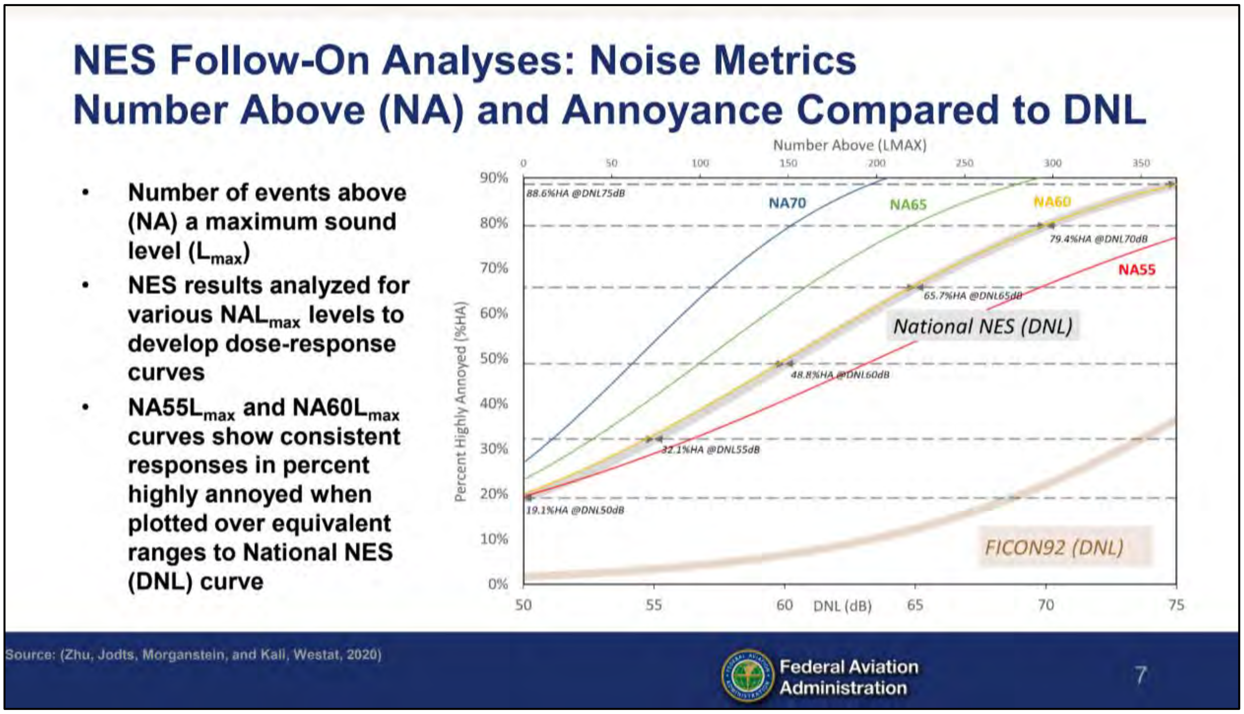


Figure 7.5-1 *Number above is shown to be a good predictor of annoyance*

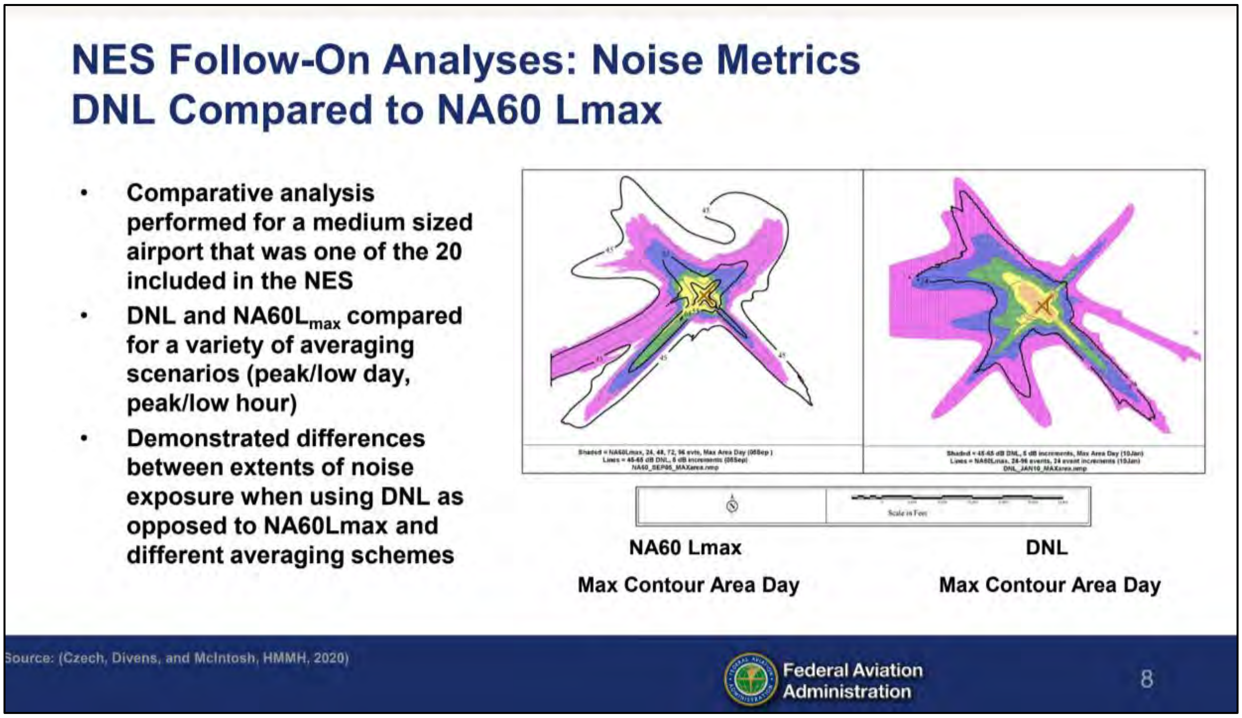
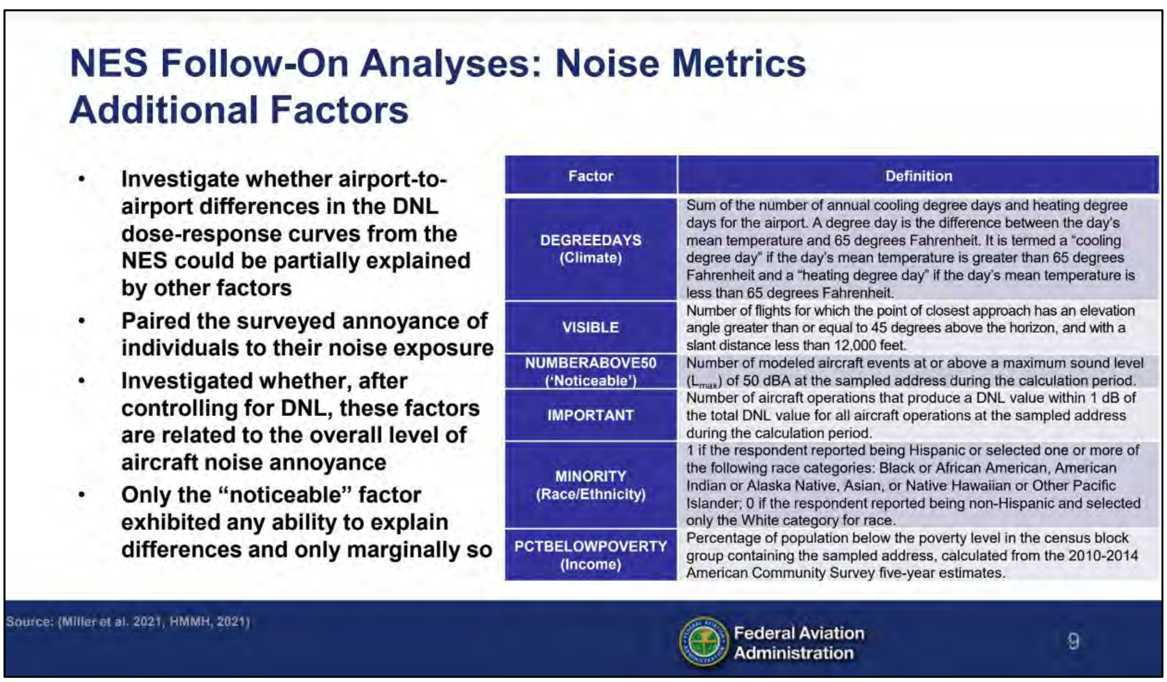


Figure 7.5- 2 *How DNL compares to number above (NA) Lmax in terms of area exposed to noise*



Factor	Definition
DEGREEDAYS (Climate)	Sum of the number of annual cooling degree days and heating degree days for the airport. A degree day is the difference between the day's mean temperature and 65 degrees Fahrenheit. It is termed a "cooling degree day" if the day's mean temperature is greater than 65 degrees Fahrenheit and a "heating degree day" if the day's mean temperature is less than 65 degrees Fahrenheit.
VISIBLE	Number of flights for which the point of closest approach has an elevation angle greater than or equal to 45 degrees above the horizon, and with a slant distance less than 12,000 feet.
NUMBERABOVE50 ('Noticeable')	Number of modeled aircraft events at or above a maximum sound level (L_{max}) of 50 dBA at the sampled address during the calculation period.
IMPORTANT	Number of aircraft operations that produce a DNL value within 1 dB of the total DNL value for all aircraft operations at the sampled address during the calculation period.
MINORITY (Race/Ethnicity)	1 if the respondent reported being Hispanic or selected one or more of the following race categories: Black or African American, American Indian or Alaska Native, Asian, or Native Hawaiian or Other Pacific Islander; 0 if the respondent reported being non-Hispanic and selected only the White category for race.
PCTBELOWPOVERTY (Income)	Percentage of population below the poverty level in the census block group containing the sampled address, calculated from the 2010-2014 American Community Survey five-year estimates.

Figure 7.5- 3 *Which additional factors could explain airport-to-airport DNL differences?*

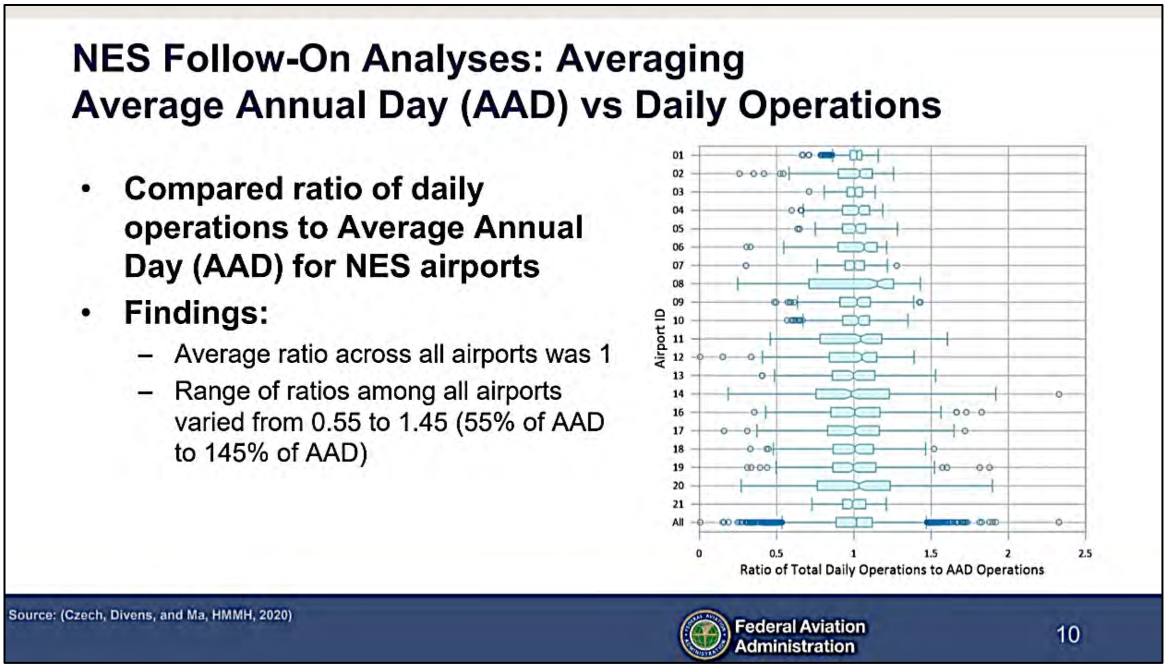


Figure 7.5- 4 Comparison of ratio of daily operations to average annual day operations

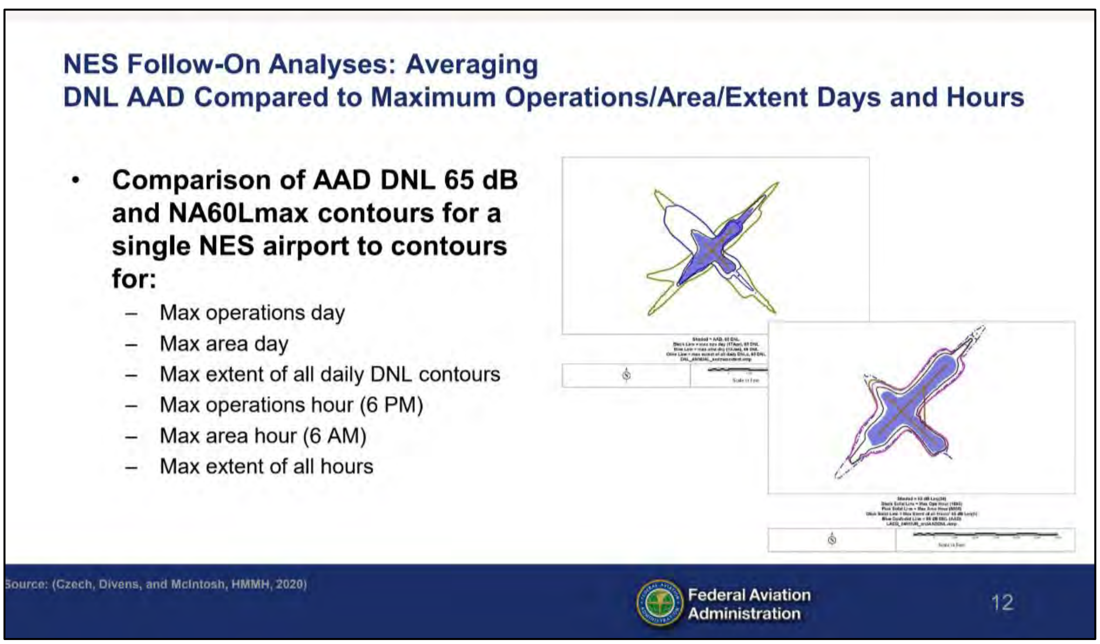


Figure 7.5- 5 Averaging approach greatly influences contour shape and size

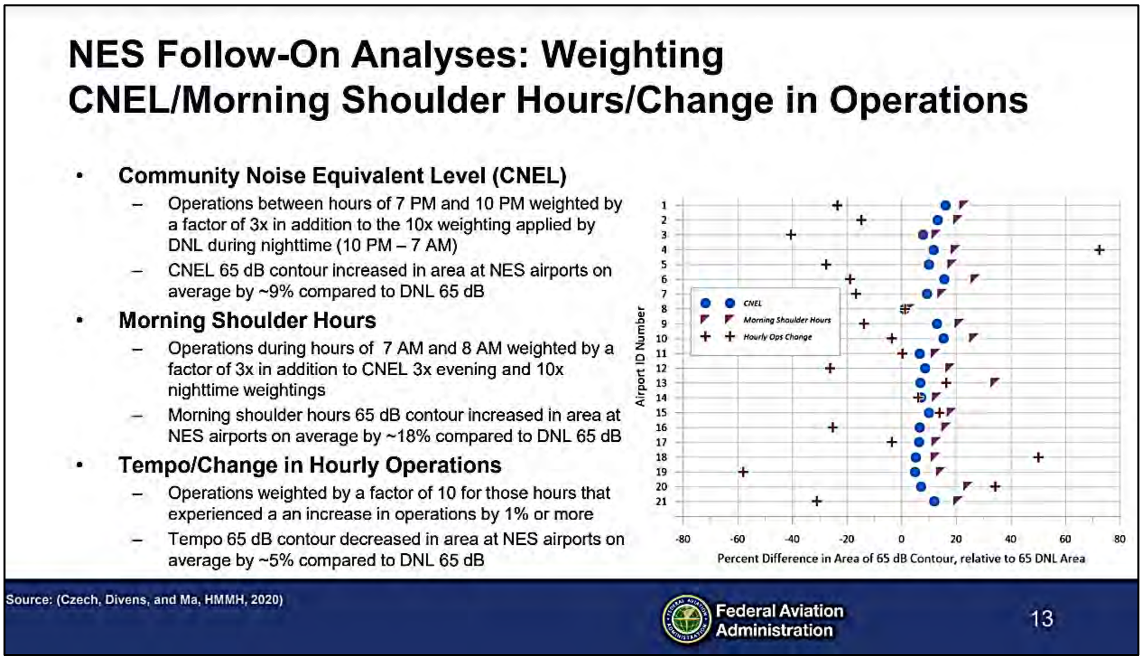


Figure 7.5- 6 Effects of weighting on contours versus DNL 65 dB

7.6 Liability of Airports in the U.S. for Noise Impacts

Peter Kirsch—Kaplan Kirsch & Rockwell

Airport proprietors can be held liable for noise impacts around U.S. airports. But, while caselaw and federal and state statutes have long allowed for compensation under certain circumstances interfering with the use and enjoyment of a property, requirements to show sufficient harm are strict and these cases rarely succeed.

Peter Kirsch, a lawyer with the law firm of Kaplan Kirsch & Rockwell, represents airports on noise issues and shared his expertise about airport proprietors' liability in the United States for noise damages. Principal issues covered were concepts of liability under U.S. law and limitations on such liability.

The law in this area draws important distinctions among the terms airport "owner," "operator," and "sponsor" (the FAA). The operator, not the owner, generally bears liability. The basis for liability relating to aircraft noise has remained remarkably constant, even as many changes have occurred in the aviation sector over the last 75 years. Beginning in the 19th century, modern law developed three different zones of property rights: surface rights, subsurface rights, and air rights.

In 1946, in the case of Causby v. United States, the U.S. Supreme Court established important principles that hold strong to this day, including the overarching principle that property owners could recover damages for injuries caused by aircraft overflights. In the case, which involved chickens that were dying as planes flew low in the area, the court held that "flights over private land are not a taking, unless they are so low and so frequent as to be a direct and immediate interference with the enjoyment and use of the land." The court held there was a "taking" because the effect of the overflights was so significant that the use of the surface property was destroyed or nearly destroyed.

One new principle that emerged from this case is that the use of airspace above a property created a servitude—an "avigation easement"—that required compensation. Also, the use of airspace above property was not compensable unless it adversely affected the real estate. And third, navigable airspace was defined as beginning at 300 feet above the ground, plus the airspace needed for takeoffs and landings.

In another key case, Griggs v. Allegheny County, the Supreme Court established that airport proprietors are the appropriate defendant in these types of cases, and are responsible for acquiring necessary easements the same way they are responsible for acquiring the airport land itself. Under this case and others that followed, courts have tended to presume that a taking has occurred for overflights below 500 feet—the generally applicable definition of navigable airspace—and that none has occurred for overflights over 500 feet.

The legal theory underlying noise liability is based on three main concepts.

- *Takings*. Under the U.S. Constitution, the taking of a property right requires compensation.
- *Trespass*. For a finding of legal liability under this principle, the aircraft must physically invade the property owner's property rights.

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- *Nuisance*. This basis for legal liability does not require physical invasion of the property, but rather only an adverse impact. Physical, not purely emotional, injury must occur.

Even given the potential liability that falls on proprietors, the concept of "constitutional preemption" holds that the federal government controls the navigable airspace. This places the vast amount of control over the operations of aircraft with the federal government and severely limits the authority of airport proprietors in this regard.

While courts have not abandoned the principles under the Griggs case, a series of cases, including those listed in Figure 7.6-1, have both limited the authority of airport proprietors on the basis of constitutional preemption and significantly decreased the ability of property owners to recover compensation. Meanwhile, statutes have reaffirmed the obligations of airport proprietors, as well. Figure 7.6-1 also lists statutes with this effect.

Figure 7.6-2 summarizes the status of current rules of noise liability, which can vary by state. The general federal rule is that liability can attach for overflights occurring directly above the property in question, below 500 feet, and with a frequency that substantially interferes with the use and enjoyment of the underlying land.

State rules can vary. As summarized in Figure 7.6.2, depending on the state, liability can follow from:

- A direct invasion of the "super-adjacent" airspace—that is, the airspace directly above the property;
- The aircraft's impact rather than its location; or
- A taking in the form of damage or injury to a property, even without complete destruction.

Principles of liability for airport noise impacts have been refined over time. For example:

- The 500-foot rule is no longer a bright line and is becoming far less relevant.
- It is becoming less important that the aircraft actually be flying overhead if the noise is particularly burdensome. More frequent but less noisy operations can be as offensive as fewer, louder ones.
- Reduction in property value is not sufficient by itself to find liability. Rather, the property owner must show interference with use and enjoyment of the property.
- Avigation easements can now be purchased for the use of airspace above a property, although these rights are usually narrowly construed by the courts.

In states that allow a finding of liability for injury rather than requiring a complete taking, a rule called the "community damage rule" has limited the ability to recover damages for noise. The property owner has to show a unique burden not shared by the community. As a result, courts have looked with disfavor on class actions and group litigation, given the unique variables of each property owner and each piece of property. This represents a significant impediment to litigation, given the expense, burden, and low likelihood of success for an individual.

Another statute, the Aviation Safety and Noise Abatement Act of 1979, established a statutory scheme for noise compatibility planning and for the creation of a noise exposure map.

The statute provides immunity from liability when noise levels are consistent with a published noise map.

With the limitations discussed, it is increasingly difficult to assert a successful claim for liability for noise, and successful cases may number less than 10 in a decade. Other takings theories may be more viable, with statutory claims under environmental laws representing a critical legal tool.

The discussion, it was noted, focused on the traditional use of aircraft over the last 100 years. It is yet to be determined how these principles will be applied in the context of new technologies and concepts such as drones and advanced air mobility.

Figure 7.6-1 *Cases and statutes affecting proprietors' authority and obligations*

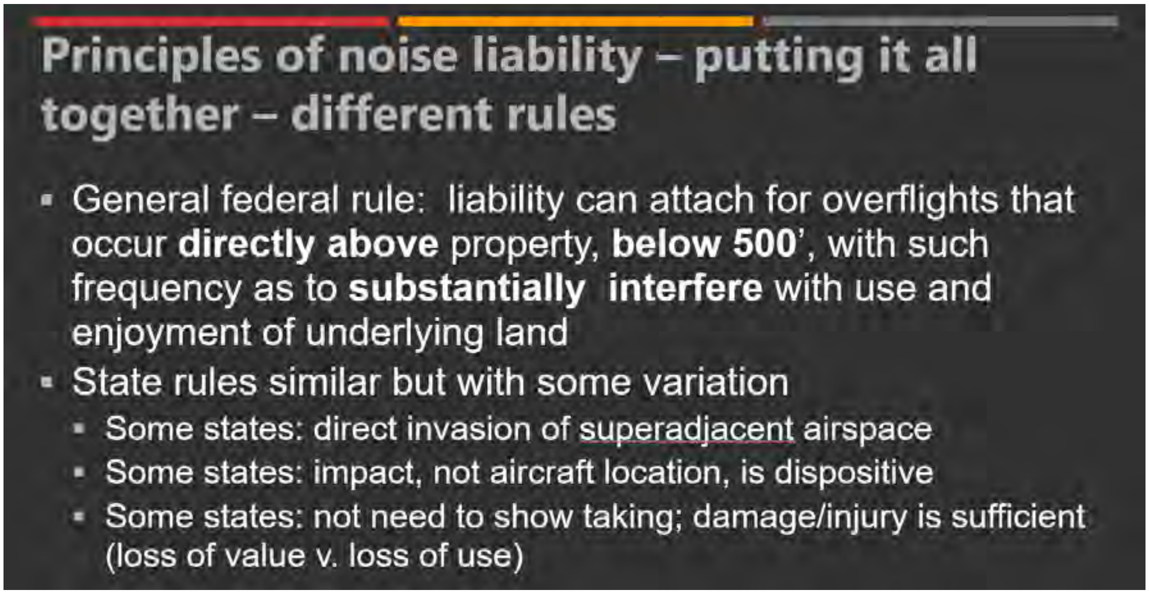

Figure 7.6-2 *Federal and state rules on noise liability vary*

8.1 Keynote Address: Noise Metrics for Airspace Redesign—A UK Perspective

Darren Rhodes—UK Civil Aviation Authority

The UK Civil Aviation Authority (CAA) is the airspace regulator in the United Kingdom (UK), with responsibility for approving changes to airspace design. The government provides legal direction and environmental guidance to the CAA regarding airspace design considerations, including those related to noise metrics and thresholds. As set forth in its Air Navigation Guidance, government priorities in the aviation arena include limiting the number of people significantly affected by adverse impacts from aircraft noise. The government has also provided guidance on valuing the impacts of noise, including aircraft noise, on health and quality of life.

Darren Rhodes shared his expertise on noise metrics used in airspace redesign from the perspective of the UK Civil Aviation Authority. Rhodes serves as the CAA's chief technical noise advisor, providing advice on issues related to aircraft noise to the CAA and also to the UK government.

Unlike some national aviation authorities, the CAA has no power to set noise-related and other aviation environmental policy. This is a responsibility of the UK government. Design and regulation of UK airspace is functionally separated, with the CAA as the airspace regulator. Above 7,000 feet, National Air Traffic Services (NATS)—the UK's air traffic service provider—is responsible for the design and operation of the airspace, while below 7,000 feet, individual airports are responsible for the design of UK airspace. Changes to airspace design must be approved by the CAA, with direction from the government, on issues including noise metrics and thresholds.

Between 1990 and 2017, the UK equivalent of 65 dB(A) DNL was the 57 dB(A) LAeq. This is a 16-hour average summer day noise indicator. In 2014, a noise attitude survey found the threshold at which 10 percent of the population is highly annoyed had come down from 57 dB(A) to 54 dB(A), with some adverse effects of annoyance seen down to 51 dB(A) LAeq 16hr. And in 2017, the government's guidance document to the CAA—called the *Air Navigation Guidance*—defined a lowest observed adverse effect level (LOAEL) of 51 dB(A) LAeq 16 hr. This change produced noise contours over three times larger in area than those based on the previous, 57 dB(A) threshold, as reflected in Figure 8.1-1 showing the respective contours around London's Heathrow Airport. The noise threshold change at Heathrow translated into a five-fold increase in population exposure, due to increased population density as the contour extends farther from the airport.

London Heathrow is a key player in terms of UK aircraft noise matters and airspace modernization, responsible for 70 percent of population exposure. Today, all of Heathrow's standard instrument departures (SIDs) are based on conventional navigation technologies (compass headings and distances relative to ground-based beacons). The last major airspace redesign, a new SID, was in 1975.

The Secretary of State for Transport has directed the CAA "to prepare and maintain a coordinated strategy and plan for the use of all UK airspace for air navigation up to 2040, including for the modernization of the use of such airspace." This strategy is called the Airspace Modernization Strategy (AMS). The AMS vision is to deliver quicker, quieter, and cleaner journeys and more capacity, for the benefit of those who use and are affected by UK airspace. The AMS objectives, updated in 2022, are to maintain and improve the UK's high levels of safety; integrate diverse users, including defense and security stakeholders; reduce complexity and improve efficiency; and strive for environmental sustainability.

In its *Air Navigation Guidance* providing direction to the CAA, the Secretary of State for Transport sets forth its air navigation environmental objectives, defines altitude-based priorities with respect to environmental impacts, and defines LOAEL for day and night.

The *Air Navigation Guidance* environmental objectives are set forth as:

- *Priority A.* Limit and, where possible, reduce the number of people in the UK significantly affected by adverse impacts from aircraft noise. The CAA is to interpret this as limiting/reducing aviation noise's *total* adverse effects on people, not based on the absolute number of people in a particular noise contour.
- *Priority B.* Ensure that the aviation sector makes a significant and cost-effective contribution toward reducing global emissions.
- *Priority C.* Minimize local air quality emissions and ensure that the UK complies with its international obligations on air quality.

The guidance directs the CAA on how to prioritize altitude-based factors when considering changes to airspace design:

- *Priority A.* In the airspace below 4,000 feet, limit and reduce when possible the total adverse effects on people.
- *Priority B.* Where options below 4,000 feet affect a similar number of people in terms of adverse noise effects, choose the option most consistent with existing airspace arrangements.
- *Priority C.* Between 4,000 and 7,000 feet, continue to prioritize minimization of aviation noise according to aviation policy, unless this would disproportionately increase CO_2 emissions.
- *Priority D.* At or above 7,000 feet, CO_2 emissions—not noise—should be prioritized.

The Department of Transport's *Transport Appraisal Guidance* (TAG) includes a module for valuing the impacts of noise, including aircraft noise, on health and quality of life. TAG values noise impacts on: annoyance, sleep disturbance, strokes, dementia, and acute myocardial infarction (heart attack).

For purposes of assessing and comparing the noise impacts of airspace changes, the government has set an LOAEL of 51 dB(A) LAeq, 16hr for daytime noise and 45 dB(A) LAeq, 8hr for night-time noise, and the CAA should ensure that these metrics are considered in airspace redesign decisions. The approach is applied in a relative manner to estimate the monetized noise impacts of an option versus a baseline. The monetary output, then, is the *change* in noise costs, not the total costs. The assessment is made for the first year of an airspace redesign, then 10 years later to account for any growth the change facilitates. A discount rate is then applied to determine an overall net present value for each option appraised.

For communities farther away from airports, not affected by noise above the LOAELs, other aspects of noise are also taken into account when different options are associated with similar total adverse effects of noise. Metrics for these purposes include the number above metrics such as N65 for daytime noise and N60 for nighttime noise.

Changes in overall numbers of overflights must also be considered. Although not a direct measure of noise, it is a metric that communities can more readily relate to, and it can be easily computed all the way up to 7,000 feet when noise calculation becomes subject to uncertainty.

The UK CAA has created a mathematical definition to calculate overflight that recognizes that overflight is perceived over an area rather than at a single point. The overflight metric, as depicted in Figure 8.1-2, is defined as an inverted cone with an elevation angle of 48.5 degrees—chosen so flights at the edge are 3 dB(A) quieter than directly overhead.

Overflight can be readily quantified for the baseline using radar data and, for future scenarios, using the same geometrical elements used for noise modeling purposes. It can be aggregated over population receptors or computed over grids from which overflight contours can be calculated and population overflight exposure tabulated. Overflight contours, which indicate the number of flights within the contour, are shown in Figure 8.1-3 with a departure example.

Noise metrics, as prioritized, are diagrammed in Figure 8.1-4. The primary noise indicator is total adverse impact above the LOAEL—51 dB(A) LAeq, 16hr in the daytime—and monetized according to the UK government's *Transport Appraisal Guidance*. Next, changes to N65 daytime and N60 nighttime are considered, and then changes in overflight including all flight paths up to 7,000 feet.

Rhodes addressed several questions during a discussion period following his presentation:

- *Why is it that airplane arrivals into Heathrow seem to be held for a time in the air before landing?*

There is a strict limit on the number of Heathrow flights before 6 a.m., so permission to land can be delayed. An attempt is being made to slow aircraft down en route rather than delay landings.

Also, Heathrow is an intensively used two-runway airport, and airborne holding can maximize runway capacity, although it does come with a carbon cost.

- *Is there a risk of discounting the experience of people very near the airport in the noise metrics used, or does appropriate weighting address this issue?*

Adverse effects are prioritized using a weighted system based on the dose-response functions. But given how contour ellipses work and also factors such as population density impacts, the total adverse cost is dominated by the bottom 3 dB(A), at the 51 to 54 dB(A) exposure level. Even with the weighting system, annoyance weighs in much more highly than acute health effects based on the sheer number of people impacted.

- *What are the cutoffs, in terms of distance out and altitude, for the noise metrics? And is consideration given to the cumulative impacts of multiple airports in the same vicinity?*

The cutoff for the primary noise contour is the LOAEL of 51 dB(A) LAeq, 16hr. The overflight cutoffs are less prescriptive and sponsors typically look at N65 down to 10 or five events. This calculation may not reflect an average kind of exposure. For overflight, the policy provides a 7,000-foot cutoff, given that noise—and overflight as a proxy for noise—is not a consideration above this altitude.

As for multiple airports in some areas, this is one issue being addressed as a master plan is developed. With the national redesign working toward precision-based navigation, airports adjacent to each other will be required to consider cumulative impacts and coordination of solutions.

- *Could you speak more about the soundproofing program for those exposed to airport noise?*

The noise insulation programs for homes are airport-funded programs, not national ones, and have recently qualified homes exposed to 60 dB(A) noise levels. With what is typically a 50 percent airport contribution for soundproofing a home, uptake has been quite low. Expansion programs in the works may offer more generous contributions up to 100 percent.

- *Could you briefly describe the quota system for granting night flights into Heathrow Airport, and the airport's noise fee system for aircraft movements?*

Approximately 16 flights are allowed per night into Heathrow, under a noise quota system. The noise quota is related to certified noise levels so, to administer the program in a fair and transparent way, the airport essentially collects the noise certificate and the flight is tracked by tail number—an administration-heavy scheme that is undertaken separately for takeoffs and landings.

While the quota count system is set by the government, noise fees—which are higher for noisier airplanes and lower for quieter airplanes—are independent of government and are generally revenue-neutral to recover airport operational costs. The goal is to incentivize a move to a quieter fleet over time.

- *Is the overflight metric simply a count within the cone?*

Yes, it is a count within the cone. Recently, it was suggested that, rather than the wide altitude range that is currently used, a weight be used akin to an acoustic weight so the overflight would be stratified in essentially 1,000-foot altitude bands.

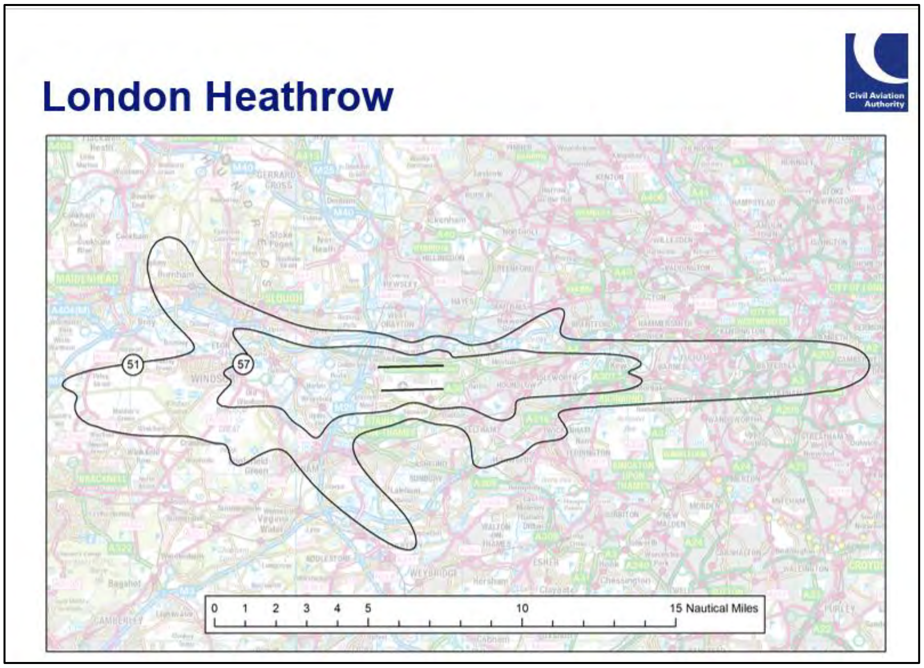

Figure 8.1-1 LAeq, 16hr noise contours: 57 dB(A) versus 51 dB(A)

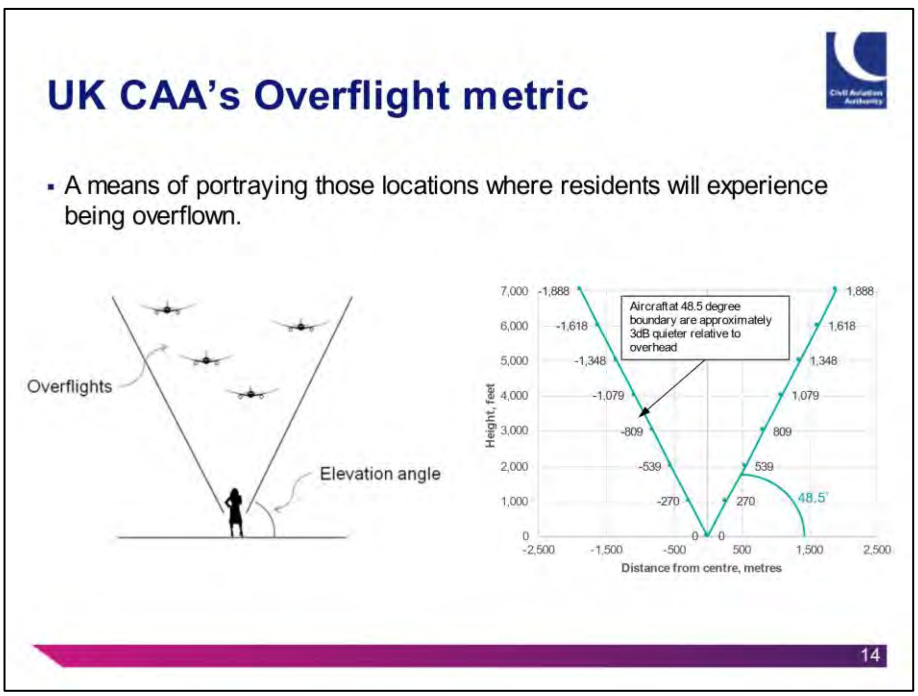

Figure 8.1-2 Overflight metric to identify affected residential areas

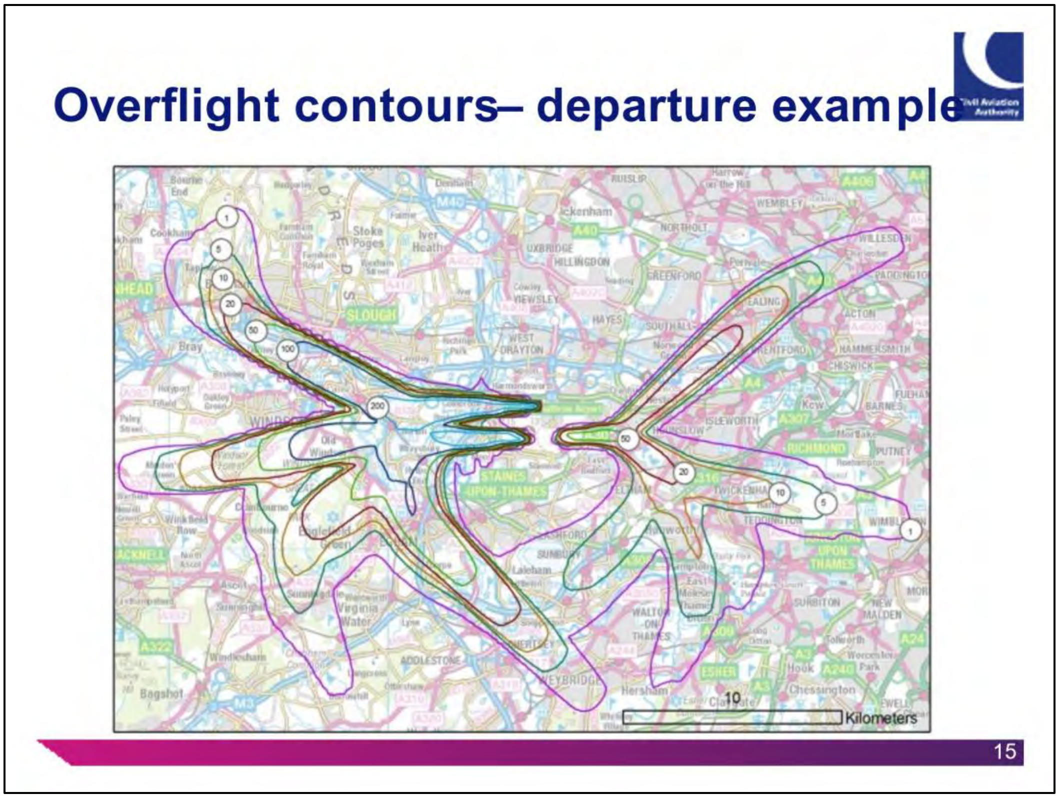

Figure 8.1-3 *Overflight contours: Departure example*

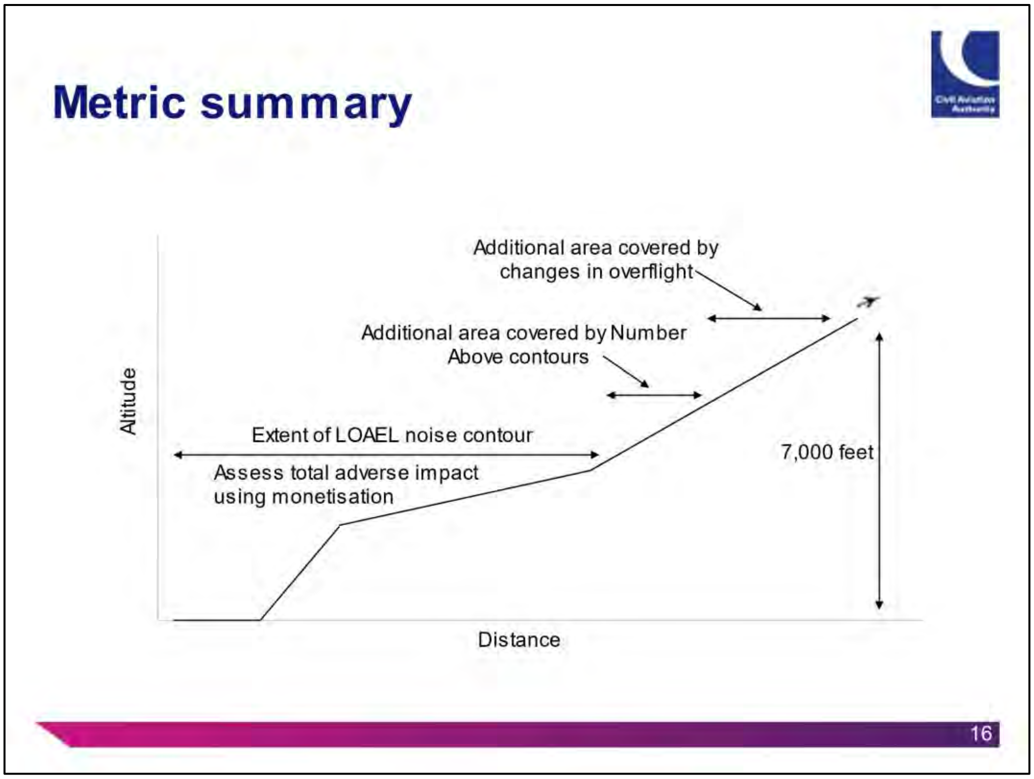

Figure 8.1-4 *Prioritized noise metrics*

8.2 Some Lessons From Quiet Drones 2022 e-Symposium

Philippe Strauss—French Center on Noise Information (CidB, Le Centre d'information le Bruit), **Jean Tourret** – INCE/Europe, and **Dick Bowdler** – INCE/Europe

The Quiet Drones 2022 e-symposium shed light on the current state of assessment, measurement, standardization, and societal acceptance in the context of noise from drones and eVTOLs. Societal acceptance of these leading-edge air vehicles can only be gained by addressing the many open questions thoughtfully and transparently. The extreme shortage of helpful data on noise from these unconventional aircraft is a prime example of a hurdle that must be overcome.

Philippe Strauss, French Center on Noise Information (CidB) project manager, highlighted select lessons from the Quiet Drones 2022 e-symposium, speaking on behalf of himself as well as presentation contributors Jean Tourret (president, INCE/Europe) and Dick Bowdler (director, INCE/Europe). The presentation focused on the specific issues of assessment, measurement, standardization and regulation, and societal acceptance as they relate to noise from drones and eVTOLs (electric vertical takeoff and landing vehicles).

Quiet Drones 2022 was the second conference of its kind, following up on the 2020 symposium during which it was established that noise was becoming a fourth hurdle (after safety, security, and privacy) with the potential to impede the widespread deployment of drones and eVTOLs. Quiet Drones 2022—developed in close alignment with similar Technology for a Quieter America efforts—was a three-day virtual conference held in late June of that year.

The 2022 symposium attracted 160 delegates from 24 countries and included 16 sessions, 20 hours of recorded presentations and extended live discussions, and 60 speakers, panelists, and chairs. The important body of information from the symposium has been summarized in a book available at no cost on the Quiet Drones website (https://www.quietdrones.org/), and is detailed in proceedings also available through the website.

Four keynote presentations on aerial mobility efforts focused on working group activities, national and international collaborations, and workshops and symposia:

- "Advancing Aerial Mobility: National Blueprint" (Nick Lappos)
- "A Summary of the 2020 NAE hosted e-Workshop: Aerial Mobility—Noise Issues and Technology" (Robert Hellweg)
- "Activities of the NASA Urban Air Mobility Noise Working Group" (Stephen Rizzi)
- "Public Acceptance and Noise Considerations in Urban Air Mobility Research—Results of DLR's HorizonUAM Project" (Bianca Schuchardt)

The first three of these focused on U.S. efforts, while the fourth focused on a European project (detailed in the next workshop presentation by Karolin Schweiger and Maria Stolz).

Eight structured sessions consisted of a total of 34 prerecorded presentations. The current workshop presentation zeroed in on three of the sessions, which focused on noise assessment, measurement and standards, and public acceptance. The three sessions are listed in Figure 8.2-1, along with the co-chairs for each. Two panel discussions, "Managing Community Noise From Drone Delivery" and "Air Taxis' Integration Into Cities, In Light of Mobility and Noise," featured prominently during Quiet Drones 2022. These panel discussions included 14 panelists, as listed in Figure 8.2-2, discussing the views of aviation authorities, aircraft manufacturers, drone operators, communities, and non-government organizations (NGOs), and presenting results of research by renowned aerospace, university, and other laboratories. Two conversation sessions were also held at the end of days 1 and 2 to facilitate informal discussions between delegates.

In summarizing lessons arising from Quiet Drones 2022 relevant to this workshop, examples linked to airport noise were highlighted. Small and medium drones were considered along with eVTOLs, given that their similarities outweigh their differences.

Several points provide helpful context for the consideration of drone noise:

- Tranquility has become a strong indicator of quality of life in cities, which are being made quieter by the introduction of traffic restrictions and quieter modes of transportation—a trend that does not include the introduction and proliferation of new transportation sources such as drones or eVTOLs.
- During the Covid-19 pandemic, reductions in airport traffic, and in turn noise, spurred community demand for an improved sound environment.
- Aerial mobility is an emerging technology that can be simultaneously transformative and disruptive for the aviation industry and aviation infrastructure.
- The term “advanced aerial mobility” is preferable to “urban air mobility (UAM),” to capture the broad range of operations contemplated.
- The term “air taxi” for eVTOLs can be misleading, as it communicates only one use of the aircraft, for moving people around, rather than a wider range of uses.

Figure 8.2-3 lists additional contextual points related to quieter drones. It is clear that noise from drones, like noise from other aircraft, can have significant health effects, and that drone noise can represent a major impediment to public acceptance and adoption of drone technology.

Drones have particular acoustical characteristics—such as unconventional noise signatures, high tonality, irritating frequency, and amplitude fluctuations—that can be more annoying than noise from road traffic or conventional aircraft. Tonal noise may be associated with a 3 to 6 dB penalty from a human annoyance perspective.

More sophisticated sound quality metrics such as Loudness, Sharpness, Roughness and Fluctuation Strength are needed to approximate the real perception of noise, and to answer questions such as “what does a ‘good UAM’ sound like?” and “what might be the impact on existing local soundscapes?” and “what will people think when a number of these machines are operating overhead?” NASA has developed psychoacoustic tests to answer these types of questions.

In the case of a quadcopter in hovering, flyover, or transition flight conditions, the most annoying maneuvers are not necessarily those with the largest sound pressure level. Operational contexts can change perceptions of drone noise—rescue operations are more acceptable to the public as compared with routine food delivery, for example. Acceptance and annoyance are also influenced by whether the drones—which fly lower than manned aircraft—are visible.

The general public and the media are largely in the dark about noise levels from drones and eVTOLs, and data are lacking. Most people do not know what a decibel is, and are unable to express how loud noise from an eVTOL or a drone is or should be. And public data is scarce for drones and eVTOLs, with thresholds of acceptable noise from these aircraft described in divergent ways by different stakeholders. Community demonstrations would therefore be "very useful," to elucidate issues related to noise from these aircraft for laypeople.

The noise emitted by a drone or eVTOL depends primarily on the machine's design and size, but also varies based on the operations and flight parameters—unlike for conventional aircraft with their relatively fixed landing and takeoff parameters. As with other aircraft, the number and frequency of flights greatly influence noise, as does vehicle aggregation in a particular area.

Given these factors, recommendations for minimizing noise impact on the population include:

- Fly over already-noisy ground traffic routes or corridors, avoiding the introduction of effects that concentrate traffic and noise in former quiet zones.
- Randomize routing, when possible—that is, do not use the same path from place to place. With more drones, it may be necessary to concentrate flights on specific routes, although this challenges the recommendation for randomization.
- Avoid routes over hospitals, schools, or homes for the elderly.
- Aim to limit hours of flight from 8 a.m. (later on Sundays) to 8 p.m.
- For deliveries, reduce the duration of the "drop" and subsequent takeoff.

The sound power produced by drones is calculated from measurements of sound pressure using microphones, and can be supplemented by directivity and frequency data. For a flying object like a drone, this information is challenging to obtain. Gathering the data requires well-defined procedures, and therefore a need exists for a set of measurement guidelines for quantifying vehicle acoustic emissions through ground and flight testing.

Depending on the size and type of machine, measurement of sound pressure levels around the source can be performed in different environments. For small- or medium-sized drones, for example, measurements may be taken inside acoustic rooms, outside on the ground or another acoustically hard surface using a turntable on a microphone stand, or by using fixed or rotating microphone arrays, as reflected in Figure 8.2-4. For eVTOLs, microphones are installed on lines and masts perpendicular to the flight path. Measurements are performed in keeping with International Civil Aviation Organization (ICAO) Chapter 8, 10, or 11, but at a much lower altitude—20 to 60 meters—in overflight, takeoff, landing, and hovering configurations.

Noise from "new entrant" aircraft is substantially different from noise from other aircraft, and new methods, limits, procedures, and metrics are needed in the context of these new vehicles. Standardization of measurement procedures is at an early stage internationally. For small and medium drones, the International Organization for Standardization (ISO) Joint Working Group 7 between TC 20 (Aircraft) and TC 43 (Acoustics) has been created and is drafting a standard for Unmanned Aerial Systems (UAS) with takeoff mass up to 150 kilograms. For eVTOLs, the ICAO has created a Committee on Aviation and Environmental Protection toward establishing sufficiently simple noise certification standards.

High-level environmental protection for citizens requires limits on noise emissions. For drones, air taxis, and traditional aircraft to share the sky, thoughtful traffic management is required, with serious consideration to noise. Industry must anticipate the regulatory framework for future products and activities. Public authorities require more information to produce appropriate regulatory frameworks. Communication between parties, including the sharing of manufacturers' data anonymously, should be encouraged and organized at the international level.

In Europe, three categories of drone operations are defined: open (low risk), specific (medium risk), and certified (highest risk). Sound power limits have been set by regulation based on the current state of the art, and these levels will be progressively reduced. Drones could come to represent a significant source of environmental noise pollution, especially as these vehicles operate closer to communities than conventional aircraft.

The deployment of drones and eVTOLs promises several potential benefits, but several downsides also exist, as summarized in Figure 8.2-5. As the state of advanced aerial mobility (AAM) evolves, engagement with—and acceptance by—the public is essential. Citizens must be informed and involved throughout the deployment of these forms of air vehicles for their various uses. "Noise remains one of the largest limiting factors in terms of public acceptance and adoption of drone technology, and engagement with the public is key in the development and acceptability of advanced aerial mobility."

Jean Tourret and Dick Bowdler joined presenter Philippe Strauss in answering questions from workshop participants. Participants inquired, given the acknowledged shortage of data, whether any specifications exist in terms of modeling data for AAM. The response: A couple of labs in Europe, as well as Airbus Helicopters, may be working on this, but modeling remains at an early stage.

Asked about a case study of noise from these emerging aircraft, the experts replied that examples are lacking, and manufacturers may be hesitant to discuss noise levels and their potential impact. While significant efforts are being undertaken to reduce the noise from drones, publication of data is rare, and it was noted that perhaps statisticians have a role in encouraging additional measurement and analysis in this sphere. Testing had begun in the six months prior to the workshop relating to measuring air taxi noise (which admittedly is very different from the noise from, say, very small drones).

A participant added that projects are ongoing in Europe, related to the "U-space" system for managing unmanned aerial systems traffic, that include different use cases of drones and eVTOLs. While noise measurement has not been a project focus, to the commenter's knowledge, it is being examined at least preliminarily.

Another participant commented that a good net assessment of societal benefits versus costs from these nontraditional aircraft requires a systems engineering perspective that considers all relevant factors. Noise is one important consideration, along with safety and many other factors. The FAA and NASA have undertaken some proving ground-type testing and have developed some dedicated sites and corridors.

Another participant added that, for the FAA's part, a small number of environmental reviews have been completed, working with operators desiring to undertake package delivery-type operations. While not superb, the data from the operators-—who have hesitated to allow FAA measurements, given the issues of competitive advantage—have been helpful to an extent. The FAA has been able to compel operators to provide some data, but has limited authority to require submission of this type of information. And the agency has already been receiving comments from the public in opposition to drone operations, based on concerns about privacy as well as noise.

In concluding the question-and-answer and discussion period, a participant informed attendees that the Society of Automotive Engineers (SAE) committee A-21 was in the process of revising the Aerospace Recommended Practice ARP4721 on measurement of aircraft noise in the vicinity of airports to include AAM and UAM vehicles (and notably, the context would not be limited to the vicinity of airports).

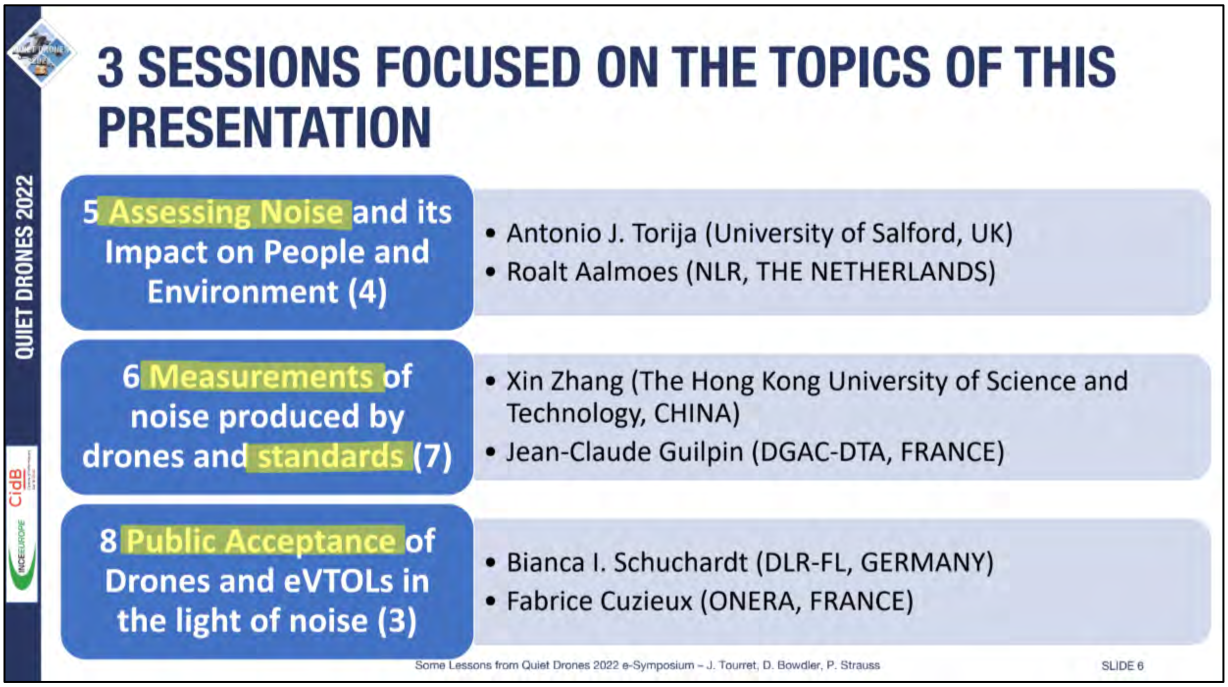

Figure 8.2-1 *Workshop presentation highlighted three Quiet Drones 2022 sessions*

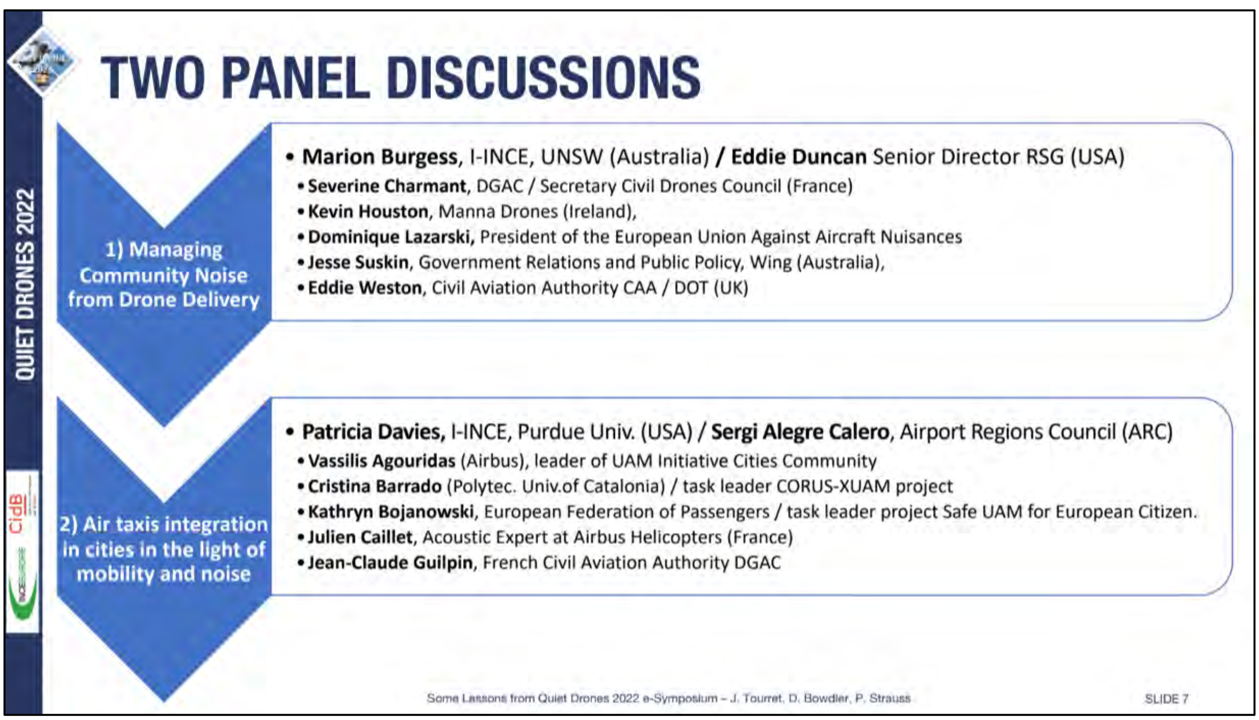

Figure 8.2-2 *Panel discussion topics and participants*

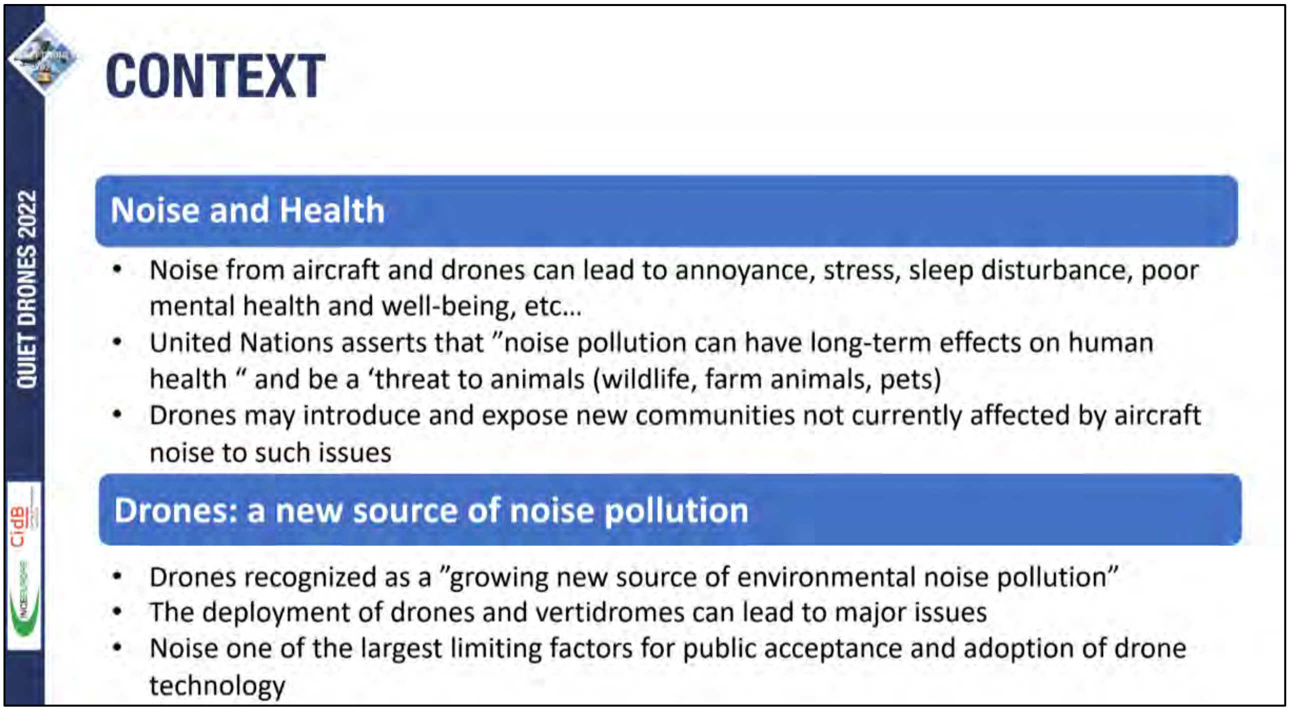

Figure 8.2-3 *Like conventional aircraft, drones can have health effects*

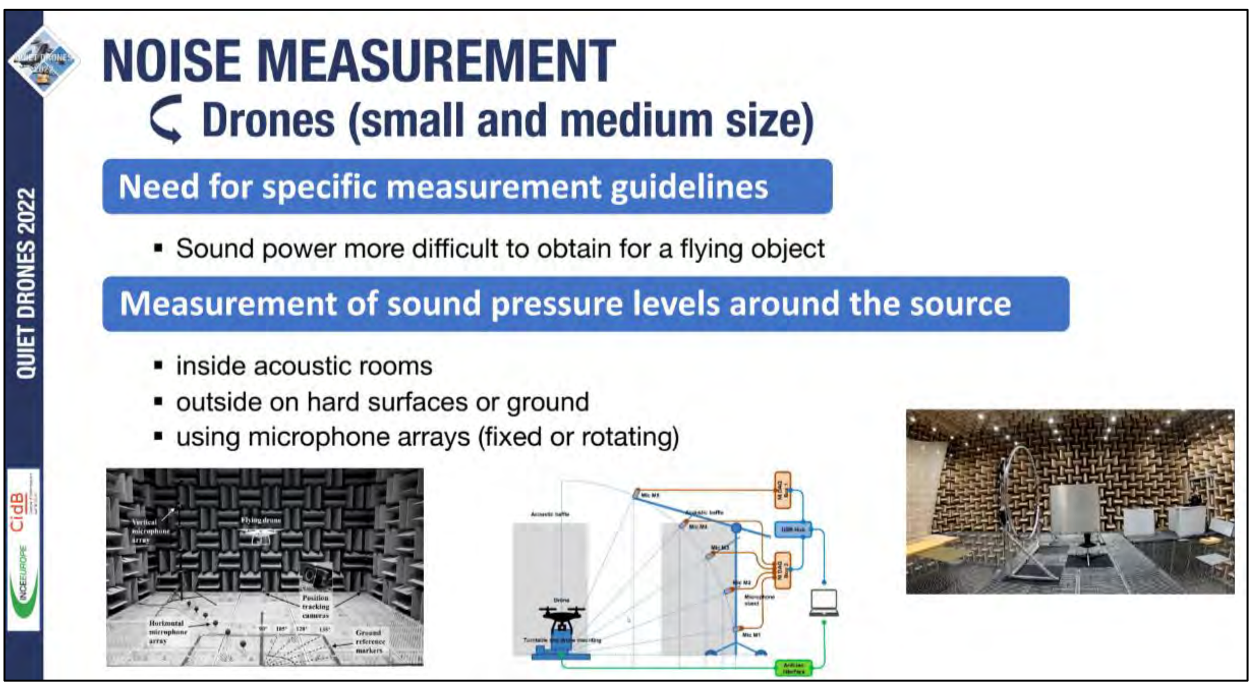

Figure 8.2-4 *Noise measurement of small/medium drones*

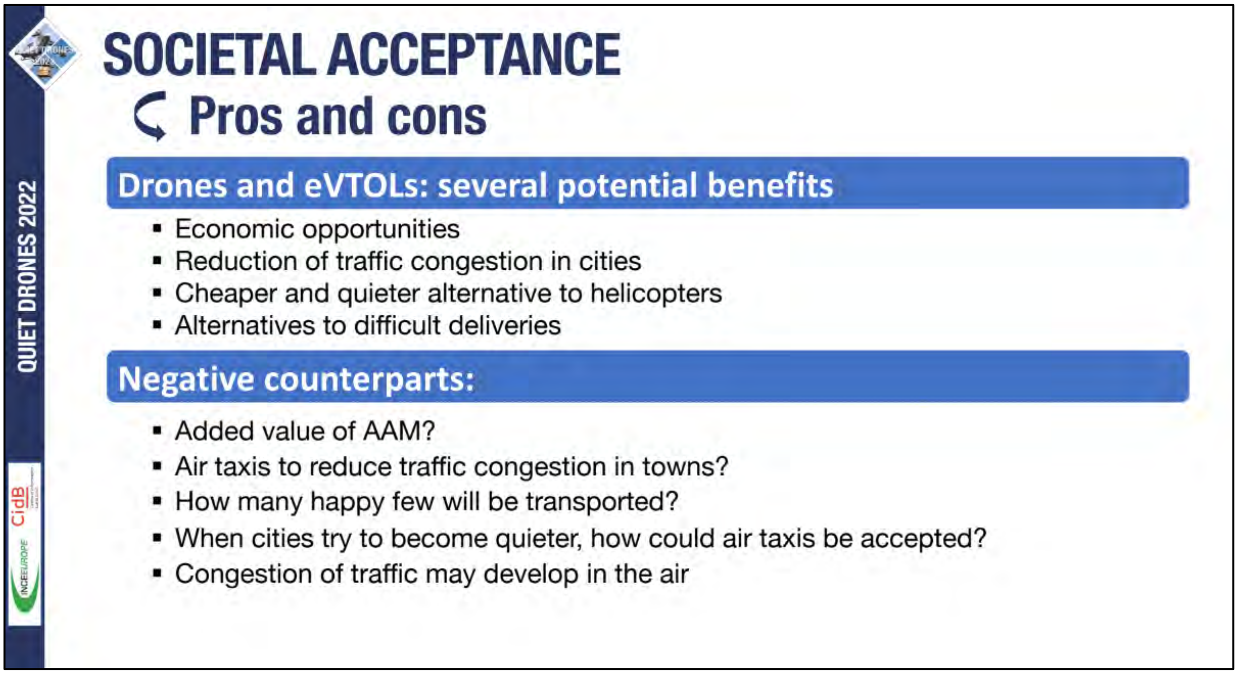

Figure 8.2-5 *Pros and cons related to societal acceptance of drones and eVTOLs*

8.3 Urban Air Mobility: Vertiport and Public Acceptance - Research at the German Aerospace Center

Karolin Schweiger and Maria Stolz—German Aerospace Center (DLR)

Public perception will be a strong determinant in whether urban air mobility succeeds as an alternate form of transportation, with noise ranking among the influential factors in community acceptance. The German Aerospace Center is conducting research, including virtual reality studies, to advance the understanding of people's responses to vehicles flying nearby.

Karolin Schweiger and Maria Stolz, both with the Institute of Flight Guidance of the German Aerospace Center, or DLR, addressed the issue of public acceptance of urban air mobility (UAM). The focus was on vertiports, which are the mobility environment's equivalent of airports.

Urban air mobility is a popular and growing topic of focus for published articles, as reflected in Figure 8.3-1. Even with all the attention, much remains to be learned about whether urban air mobility will be successfully integrated into the transportation system.

In Germany—where a huge proportion of residents live near public transportation—the question has been raised whether UAM is mere hype or promises to revolutionize mobility. One question being considered: What must UAM offer to attract prospective passengers and have a meaningful impact on society?

The key is multimodality. "We see urban air mobility as a transportation concept that is incorporated into already existing transportation networks. And we need to make sure that it is not only about the prominent vertical takeoff and landing (VTOL) aircraft, but also about vertiports and air traffic management, which in combination can provide access to urban air mobility services, and which are responsible for operating a safe and efficient service."

In terms of vertiports, the DLR's focus is on what performance capabilities must be offered to process a certain demand distribution. For that, it must be possible to evaluate the asset traffic flow of a vertiport and gain insights about vertiport size, layout, and operational concept, which may affect how society perceives the vertiport.

DLR's HorizonUAM project is assessing opportunities and risks of air taxi operations in the urban environment. The effort covers four major topics for research: development of eVTOL aircraft, assessment and development of ground and air infrastructure, and public and social acceptance, as well as safety and security. The three-year project is expected to be completed in 2023, and DLR will publish the results in a *CEAS Aeronautical Journal* special issue.

HorizonUAM examined European regulations relating to VTOL aircraft design, propulsion systems, and U-space and vertiport operation (see Figure 8.3-2) and found little reference to noise issues. Because UAM vehicles emit noise during operation—with each emitting a noise that can differ substantially from other current and future aircraft—it is important to consider the prospective noise profiles during the development of a UAM network system.

Where vertiports are concerned, certain design criteria can help enhance public acceptance, and location is one important parameter in this regard. Various options for location are shown in Figure 8.3-3. If a vertiport is placed in a rural area rather than in the city, fewer people living nearby translates into

DLR Deutsches Zentrum für Luft- und Raumfahrt decreased disturbance. In the case of urban air mobility, however, vertiports will necessarily be located in urban areas—atop existing transportation hubs or buildings, for example. While noise may in that case blend with existing urban noise, the overall increase in noise may be considered problematic by the community. The bottom right image in Figure 8.3-3 shows a vertiport proposal incorporating a rim designed to protect the community from noise.

Ground operation is another key parameter, with different approaches possible for eVTOLs. A conveyor belt or a device docked underneath could move the vehicle around, for example. Landing gear could be electrically powered, which is much quieter than traditional propulsion systems used today for conventional fixed-wing aviation. Alternatively, operations could take place from a vertistop providing only a landing and take-off pad.

As the possibility nears that drones will fly in cities—and, that is, over people—perception and acceptance of people on the ground must be investigated. Numerous studies already indicate that visual or acoustic pollution from drones could negatively affect public acceptance [see references 1-6].

For DLR's part, the center has conducted experiments recently using virtual reality (VR), to give people a sense of what future drone traffic might be like. Two experiments were conducted in 2021—one within HorizonUAM and the other one under iUSIM (interinstitutional, modular urban mobility simulation infrastructure).

The HorizonUAM study examined how people perceive drone flights in a city center environment, and in particular, how acceptance is affected by the drones' flight height, visual density (how many drones are flying in the area), and noise. Additionally, people's experience with an air taxi landing was studied.

The 47 study participants were shown VR simulations with different scenarios, including five flight altitudes ranging from 10 to 100 meters, and three progressively increasing visual densities. To measure the effect of drone noise under different circumstances, participants experienced each scenario once with drone noise and once without drone noise. The final scenario reflected the landing of an air taxi near the participant, onto the rooftop of a bus station. Figure 8.3-4 presents a snapshot of different scenarios, as well as some details of the resources used—octocopters for the smaller drones and Volocopters for the air taxi, for example.

Acceptance was rated by participants on a seven-point scale after they experienced each VR scenario. Participants were asked questions such as whether they felt comfortable or nervous in the scenario. Key points related to the study and its findings are presented in Figure 8.3-5.

The research indicated a consistently lower acceptance for flights at lower altitudes, which is in line with previous studies. In terms of visual density, responses were more negative when a higher number of drones were in the scenario.

For drone noise, no significant effect on acceptance was observed. Drone noises may have been masked by other sounds such as road traffic, given the city center environment. This aligns with other research, including a 2020 study by Torija, Self, and Li [see reference 7]. In the air taxi scenario, the research team also observed significantly more negative perception in the visual density scenarios compared with a scenario without drones. Results showed a low to medium annoyance rating from the air taxi noise.

Participants not only provided acceptance ratings after experiencing each scenario, but also answered questionnaires before and after going through the simulation. Most participants held the same or more positive opinions of drones after the experiment, but 25 percent expressed more negative attitudes afterward. The researchers found a significant decrease in concerns related to privacy and noise after experiencing the simulation. Specifically, on a seven-point scale, the mean value in terms of privacy decreased from 5.49 before the simulation to 4.89 after. For noise, the mean value decreased from 4.34 to 3.79. For those interested in additional detail about the study, the research article was published at the Digital Avionics Systems Conference (DASC) 2022 [see reference 8].

As for the second DLR virtual reality study, an iUSIM project, information is available on YouTube, at https://www.youtube.com/watch?v=4XFbLgkRpmM ("Development of a multimodular simulation infrastructure in the iUSIM project"). The study took a more qualitative research approach than the HorizonUAM project, and included nine participants. The four research scenarios focused on how people experience drones in different areas of a city, as depicted in Figure 8.3-6: on a main street, in an industrial area, in a residential area, and in a park. The study presented different use cases of passive delivery, hobby drones, air taxis, and others, using various flight maneuvers at realistic flight altitudes.

Participants were able to move around the simulated world on a movable omnidirectional platform to undertake their study tasks, while wearing VR glasses. Acceptance was analyzed based on answers to questionnaires, and by the use of "trigger press" controls in participants' hands that they were instructed to press when they felt discomfort or annoyance.

Perception of drone flights was found to be different among the four scenarios, with drones seeming to be better tolerated in industrial areas. These zones might already be quite noisy and, according to interviews, participants would expect more drones in these areas.

On the other side of the spectrum, participants expressed the highest annoyance in residential areas—both in interviews and when using their trigger presses. A high number of trigger presses was observed when a drone was flying around a house in a residential area and also when a hobby drone was flying in a private garden. And based on interviews, small drones used for racing or filming were perceived as annoying because they sometimes conveyed a feeling of being observed, or they were very close and therefore very noisy. Also, their flight behaviors seemed unpredictable to participants. Participants most feared noise from drones, and their misuse for criminal actions.

In conclusion, the two experiments reveal that acceptance is important to address in the context of urban air mobility. Flight height, number of drones, and area of flight affect people's perceptions of drones, and these factors should be considered when planning drone missions and developing flight regulations, to avoid disturbing citizens.

During the question-and-answer opportunity following the presentation, the speakers were asked about whether safety concerns for those on the ground came up during the DLR virtual reality research. Where the behavior of small drones, in particular, seemed unpredictable, some people did express concern about safety. In an upcoming study, the research team will examine people's responses to a virtual reality experience of an air taxi flight. Safety—including what makes passengers feel safe in the small cabin of the air taxi—could arise as an important topic in this context.

In response to another question, the presenters highlighted their goal of following up on these 47- and nine-participant studies with research that includes many more participants and focuses on representing the diverse general population that stands to be exposed to UAM noise.

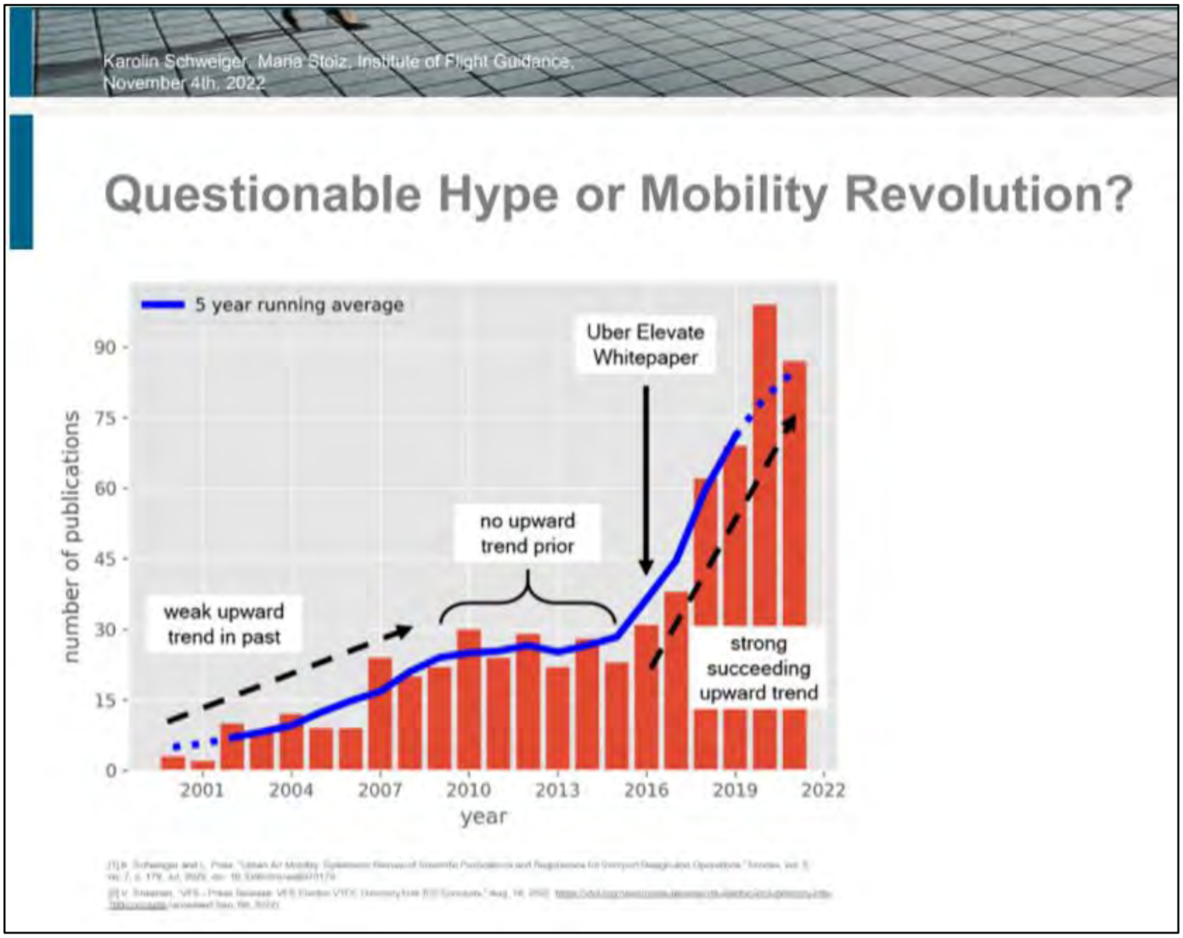

Figure 8.3-1 *Urban air mobility has been gaining ever-increasing attention*

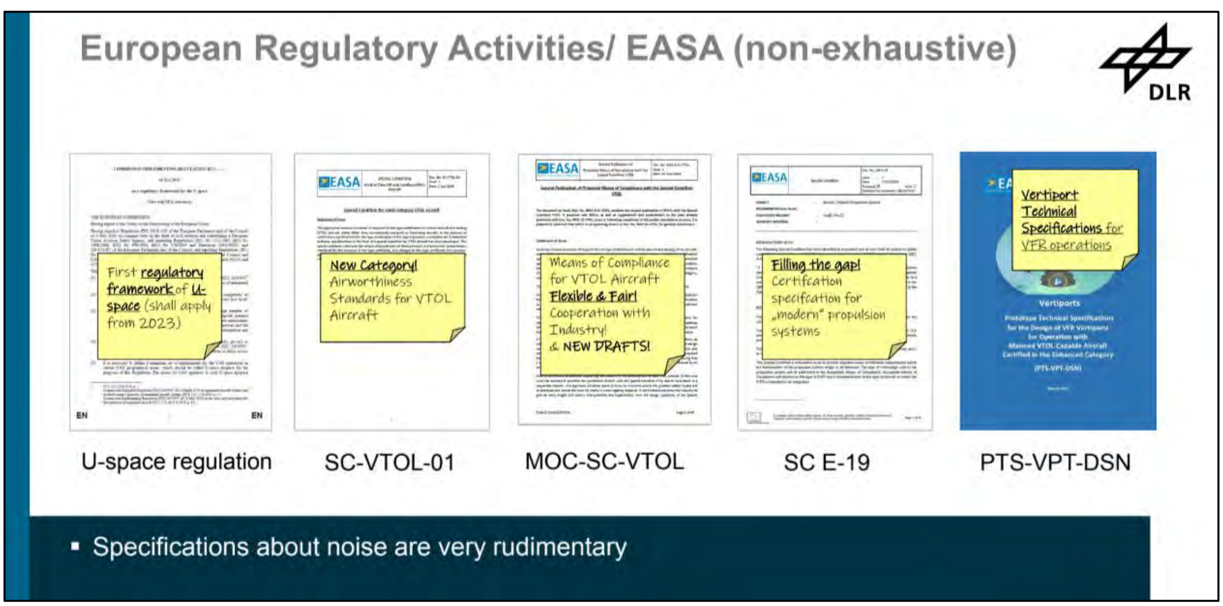

Figure 8.3-2 *European regulatory activities*

Figure 8.3-3 *Location as important factor in community noise effects*

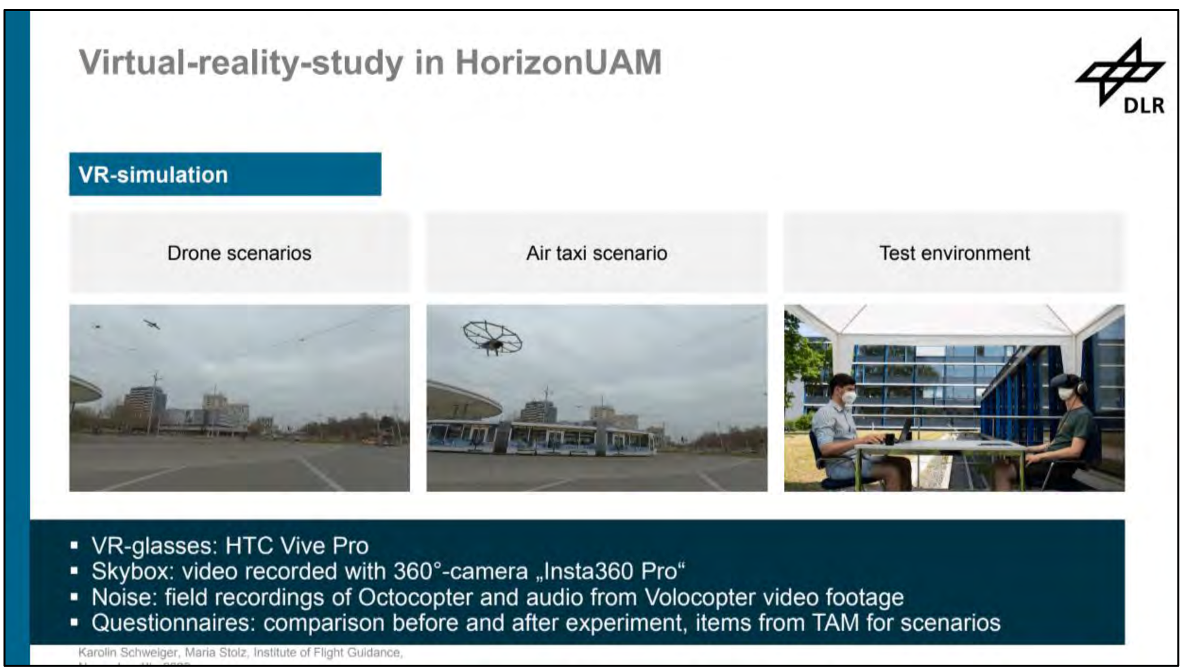

Figure 8.3-4 *Representative VR simulation scenarios in HorizonUAM*

Virtual-reality-study in HorizonUAM

DLR

- 47 participants
- Flight height: significant effects in three of the eight items, all indicating a lower acceptance for lower flight heights > similar to Hui's research [9]
- Visual density: significant effects observed on all items, responses more negative the more drones were visible
- No evidence for drone noise having a significant influence on acceptance > drones noises might have been covered by other traffic noises (also see study Torija, Self & Li, 2020)
- Air taxi scenario: all items were rated significantly more negative compared to baseline measurement, low to medium annoyance of noise
- Attitudes on drones mostly stayed the same or turned more positive after simulation experiment
- Participant's concerns on drones related to privacy and noise significantly decreased after simulation experiment

Figure 8.3-5 *HorizonUAM: Key points and findings*

Figure 8.3-6 *Snapshots from a VR session at four location types*

1. Ferreira, T. and S. Kalakou. *Strategic Planning for Urban Air Mobility: Perceptions of Citizens and Potential Users on Autonomous Flying Vehicles*. in *Conference on Sustainable Urban Mobility*. 2020. Springer.
2. Walther, J., et al., *How people make sense of drones used for atmospheric science (and other purposes): hopes, concerns, and recommendations.* Journal of Unmanned Vehicle Systems, 2019. **7**(3): p. 219-234.
3. Lidynia, C., R. Philipsen, and M. Ziefle, *Droning on about drones—acceptance of and perceived barriers to drones in civil usage contexts*, in *Advances in human factors in robots and unmanned systems*. 2017, Springer. p. 317-329.
4. Chang, V., P. Chundury, and M. Chetty. *Spiders in the sky: User perceptions of drones, privacy, and security*. in *Proceedings of the 2017 CHI conference on human factors in computing systems*. 2017.
5. Yedavalli, P. and J. Mooberry, *An assessment of public perception of urban air mobility (UAM).* Airbus UTM: Defining Future Skies, 2019: p. 2046738072.1580045281-1681120550.
6. Hui, C.J., et al., *Quantification of the psychoacoustic effect of noise from small unmanned aerial vehicles.* International Journal of Environmental Research and Public Health, 2021. **18**(17): p. 8893.
7. Torija, A.J., Z. Li, and R.H. Self, *Effects of a hovering unmanned aerial vehicle on urban soundscapes perception.* Transportation Research Part D: Transport and Environment, 2020. **78**: p. 102195.
8. Stolz, M. and T. Laudien. *Assessing Social Acceptance of Urban Air Mobility using Virtual Reality*. in *2022 IEEE/AIAA 41st Digital Avionics Systems Conference (DASC)*. 2022. IEEE.

8.4 Aircraft Technology Pathways to Quieter and Sustainable Airports

Russell Thomas, Ian Clark, and Yueping Guo—NASA Langley Research Center

Sophisticated NASA research in areas including propulsion airframe aeroacoustics (PAA) and aircraft system noise (ASN) represents progress toward substantial noise reduction around airports. NASA investigators, in collaboration with research partners, are continually improving noise reduction capabilities through increasingly accurate noise prediction methods, as well as development and testing of advanced concepts and technologies.

Russell Thomas spoke about aircraft technology as it relates to quieter, sustainable airports. The speaker and his co-authors, Ian Clark and Yueping Guo, conduct research as members of the Aeroacoustics Branch of the NASA Langley Research Center. In opening his remarks, Thomas acknowledged the NASA Advanced Air Transport Technology (AATT) Project for sponsoring his team's research.

Research collaborations in the area of propulsion airframe aeroacoustics and aircraft system noise include NASA partners and also colleagues in industry and academia. Figure 8.4-1 provides an overview of the types of research and products studied by Thomas and his research colleagues. The team performs experiments in areas ranging from fundamental acoustics to technology and vehicle concepts, in the lab and using wind tunnel flight tests. Together, these experiments and methods help in the development of new prediction methods and capabilities, prediction of total aircraft noise from current and emerging aircraft, and development of design options and technology roadmaps toward achieving NASA's noise reduction goals.

New noise reduction technology can be integrated as a retrofit into the current fleet or into the design of upcoming industry products. In terms of future aircraft, NASA works on predicting noise in both the near term and the far term, with more technical risk in the far term. Noise reduction can be evaluated in terms of three major categories:

- Aircraft technology levels (e.g., design points, structural weights, propulsion architectures);
- Technologies incorporated specifically for noise reduction; and
- Advanced configurations, referring to types other than conventional engine-under-wing designs.

Given the difficulties associated with integrating modifications within a highly constrained system, only a few design modifications and technologies have been introduced to date specifically to reduce aircraft noise. These include duct liners, increased rotor stator spacing, swept stators, spliceless liners, and conventional and propulsion airframe aeroacoustic (PAA) chevrons.

The PAA chevron exemplifies NASA's collaboration with Boeing. The chevron's two-year path from concept to flight is overviewed in Figure 8.4-2. The driving innovation was an approach focused on propulsion airframe aeroacoustic integration, in this case the flow asymmetry created by the pylon.

The jet-pylon interaction was studied in fundamental experiments and computational research, after which NASA partnered with Boeing for a major aeroacoustic wind tunnel experiment that validated the asymmetric design of the PAA Chevron for superior noise reduction. The next step was full-scale flight testing on the Quiet Technology Demonstrator 2 in 2005. Flight test results validated the improved noise reduction using this chevron, with its nozzle's clear variation from top to bottom. Boeing advanced the technology for product insertion on its 747-8 aircraft.

Another successful effort that reached the flight test level is summarized in Figure 8.4-3. In 2018, two acoustic liner technologies developed by the NASA Langley Liner Physics Team were incorporated into the Quiet Technology Demonstrator 3 inlet. The slotted facesheet perforations had been shown through extensive testing at NASA Langley to reduce drag compared to conventional facesheets. Because this flight test used existing tooling, it is likely that the 30 percent drag reduction achieved could be exceeded in the future.

The multi-degree of freedom acoustic liner core achieved fan inlet component reduction by increasing the attenuation bandwidth. Noise reduction was achieved at all three regulatory certification measurement points. At the aircraft level, the noise reduction was improved over conventional approaches, by 0.7 EPNdB, cumulative. (Editor's Note: the cumulative noise level is the arithmetic sum of "effective perceived noise level" (EPNL) values in dB measured at three FAA aircraft noise certification measurement points.) The decision is left to Boeing on incorporating this new noise and drag reduction technology into its future products.

In a 2020 PAA and aircraft system noise (ASN) flight research test with a Boeing 787, one test condition included banking the aircraft with only one engine at high power. This, together with the instrumentation design, supported the demonstration of PAA effects in flight and the validation of NASA's PAA scattering predictions. NASA is exploring possible applications using the software. For example, they have predicted the scattered field on a 4,000-foot by 4,000-foot ground plane when both engines are running at high power and the aircraft is banking at 35 degrees. In these conditions, noise increases are seen to one side of the aircraft and noise reductions are seen to the other side of the aircraft.

The process overviewed in Figure 8.4-4 is used to develop an aircraft concept and assess it for noise. Once a concept aircraft is developed, the overall concept is refined by the System Analysis and Integration Team, different groups model the propulsion system and airframe assuming a certain technology level, to ensure components are well matched. Then, detailed flight characteristics are calculated for a given mission, such as noise certification conditions. The resulting data are used to compute total aircraft system noise based on noise from each component and from interactions. Noise reduction technologies may also be added. These calculations result in an acoustic assessment that includes many types of diagnostics and results, including ground noise contours.

NASA is also progressing toward a major upgrade in its aircraft noise prediction capabilities, including prediction of airframe noise sources. With their physics-based formulations, the methods are very efficient and flexible. Comparison is made with the highest-quality data from the NASA-Boeing flight test on the 787, and the noise level and EPNL predictions are excellent over all angles. The slat component noise prediction was also excellent, from 30 to 120 degrees—the most important angles for the integrated metric of EPNL. The methods performed well for the range of aircraft operations around airports.

Propulsion airframe aeroacoustic integration effects can result from flow interactions and from acoustic scattering effects. Prediction of PAA scattering effects from reflection, shielding, and diffraction are important in achieving more accurate and realistic predictions. The NASA Langley research team has been predicting PAA effects for more than a decade using complex wind tunnel experimental data obtained in collaboration with Boeing.

The transonic truss-braced wing (TTBW)—a Boeing concept that NASA has been researching for several years—represents a promising aircraft configuration. The "N3"-level technology is shown and summarized in Figure 8.4-5. The truss structural support allows for a very high-aspect-ratio wing for reduced fuel burn. Unconventional airframe noise aspects and unique PAA scattering effects result from the high wing with strut. From NASA's studies, it has become clear that the TTBW has inherent noise advantages resulting in a 5.3 EPNdB cumulative noise reduction relative to an equivalent conventional configuration. As reflected in the figure, the roadmap technologies have a substantial noise benefit of over 7 EPNdB, with different results between the two aircraft.

An assessment of an even more advanced, "N2" technology, depicted in Figure 8.4-6, helped quantify the noise impact of the inherent airframe and engine technology. The aircraft is a single-aisle, 160-passenger tube-and-wing (TW) vehicle. Using the full roadmap of noise reduction technology, the final result of 27.4 EPNdB cumulative below stage 5 could be compared with the 20.5 EPNdB cumulative in the previously discussed aircraft. The difference of about 7 EPNdB quieter therefore provides an approximate quantification of the total result of incorporating the more advanced technology level (from higher bypass ratio engines and lighter-weight materials, for example).

On the figure's right side is the breakdown of the impact at the cumulative level of each roadmap technology. Several effective technologies applied to several noise sources, and PAA effects, are needed to achieve the 7 EPNdB total noise reduction, and each technology's impact varies based on the aircraft.

Another major category of noise reduction is the aircraft configuration and the associated PAA effects. Figure 8.4-7 shows three configurations. Researchers determined the impact of each configuration itself on cumulative noise. The first result excludes each aircraft's PAA effects from the calculation, achieving an approximately 5 EPNdB cumulative difference attributable to low-speed performance for takeoff and landing. The middle result includes predicted PAA effects, providing a more accurate assessment of the true difference, with the hybrid wing body (HWB) found to be a total of 16.1 EPNdB cumulative quieter compared to the tube-and-wing (TW).

For the final result, additional technologies are considered, including a category that can improve the PAA characteristics. This adjustment increases the noise advantage to more than 20 EPNdB cumulative. Based on this work, it is fair to conclude that these types of configuration technologies—even with smaller changes—could represent a significant innovation in noise reduction.

Electrified aircraft propulsion is an active area of research, particularly for smaller aircraft, as battery technology matures. NASA is researching the infusion of electrified propulsion into larger commercial transports. A promising focus is to develop unconventional configurations, which offers a much more significant noise benefit than simply switching out the power source in the conventional tube-and-wing configuration.

NASA concepts, including the hybrid wing body, promise significant noise shielding for potentially transformational low-noise aircraft. Achieving these noise benefits requires consideration of noise at the design stage.

With a focus on single-event aircraft noise, NASA can also predict ground contours by calculating the noise levels at thousands of observer locations. A future vehicle, at almost 35 EPNdB cumulative below Stage 5 requirements, results in an 88.3 percent reduced ground contour area exposed to a sound exposure level (SEL) greater than 85 dBA compared to a NASA modeled early-generation 777-like aircraft. The quietest concept NASA has studied—the hybrid wing body with NASA's full technology roadmap—promises a 94.4 percent reduction compared to the 777-like aircraft.

The research can stimulate the innovation of new noise reduction approaches with more near-term application for sustainable growth. It is industry, though, that will decide what is a competitive product and make the investment and bear the risk.

While significant improvements are being made in NASA's system noise capability, the agency is yielding new understanding with continued analysis and by progressing PAA scattering methods and airframe noise source prediction for a greater range of options going forward. As for increasing the implementation of noise reduction in the fleet, simply increasing the portfolio of noise reduction technology available to industry would stimulate implementation because more good options would be available for product design. Beyond discovery of innovative ideas, focused development steps must be undertaken, with more flight research to accelerate maturation. And even beyond testing a technology, properly designed research can provide unique information that would not otherwise be available. These areas of focus are outlined in Figure 8.4-8.

The future of reduced-noise aircraft is hopeful. "From our point of view as researchers, we see real potential for innovative technologies and approaches for noise reductions. As always, to reach higher technical readiness in a way that is most helpful to implementation in the fleet, of course, there will be the need for timely and well-structured collaborations between NASA and industry."

In response to a participant's question, Thomas stated that open rotors are a major topic for consideration. While great progress has been made on the source level noise of open rotors the lack of a duct with acoustic liners continues to make the comparison with ducted turbofans less favorable for open rotors. The integration with the airframe remains a significant challenge as does public perception of the large rotors seen very prominently out of the aircraft windows. A possible approach to obtaining the fuel burn benefit of open rotors together with lower noise (to the community) is through an unconventional configuration with favorable PAA integration effects.

Another attendee raised the issue of the adverse carbon impacts due, for example, to the added weight of the aircraft from noise reduction technology. While NASA is focused on advancing innovative concepts, the organization is meanwhile mindful of the range of likely impacts and prioritizes concepts with promising characteristics. Thomas highlighted that concepts such as the "pod gear," in an early phase of study, show potential to reduce aircraft weight if they can be successfully integrated. In another example, the technology highlighted in Figure 8.4-3 has been shown to reduce drag.

Finally, asked about the challenges addressing airframe noise from approach flight paths stretching farther from the airport, Thomas stated that a balance is sought by research organizations between airframe noise research and engine noise research and that the technology roadmaps shown in this presentation include many airframe noise reduction concepts. "To achieve more significant levels of noise reduction, it is clear you have to work on all aspects of noise." The presenter also pointed out the fact that aircraft climb very quickly on takeoff, contrasted with a 3-degree glide slope on approach compounding approach noise impacts.

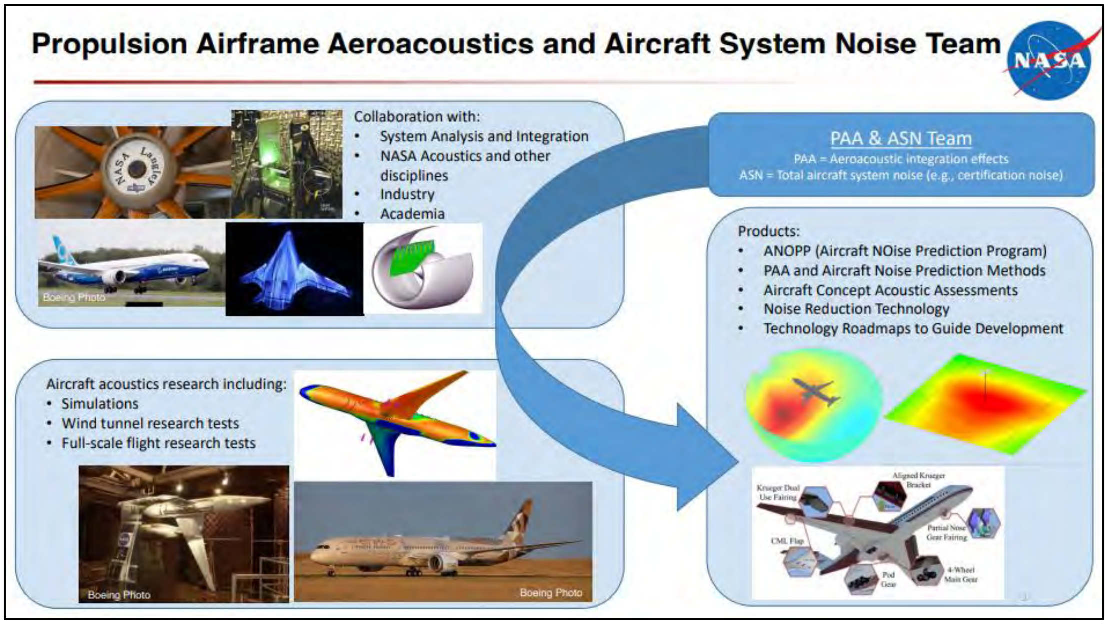

Figure 8.4-1 *Research team's collaborations and study areas*

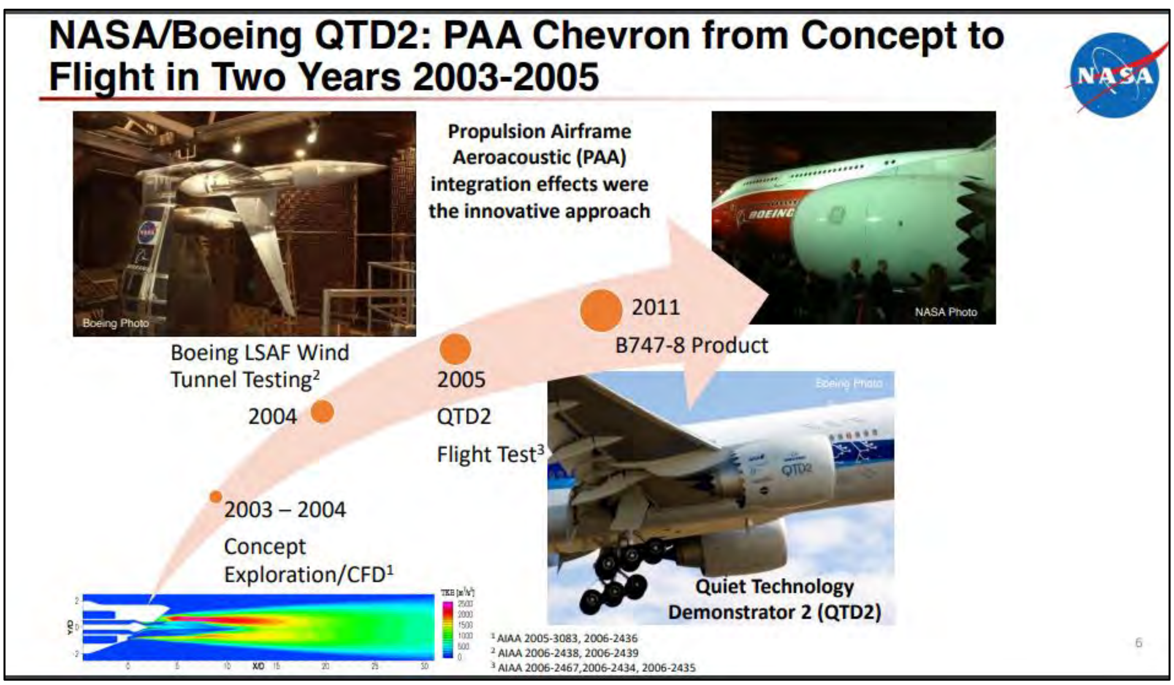

Figure 8.4-2 *PAA chevron: Progress from concept to flight*

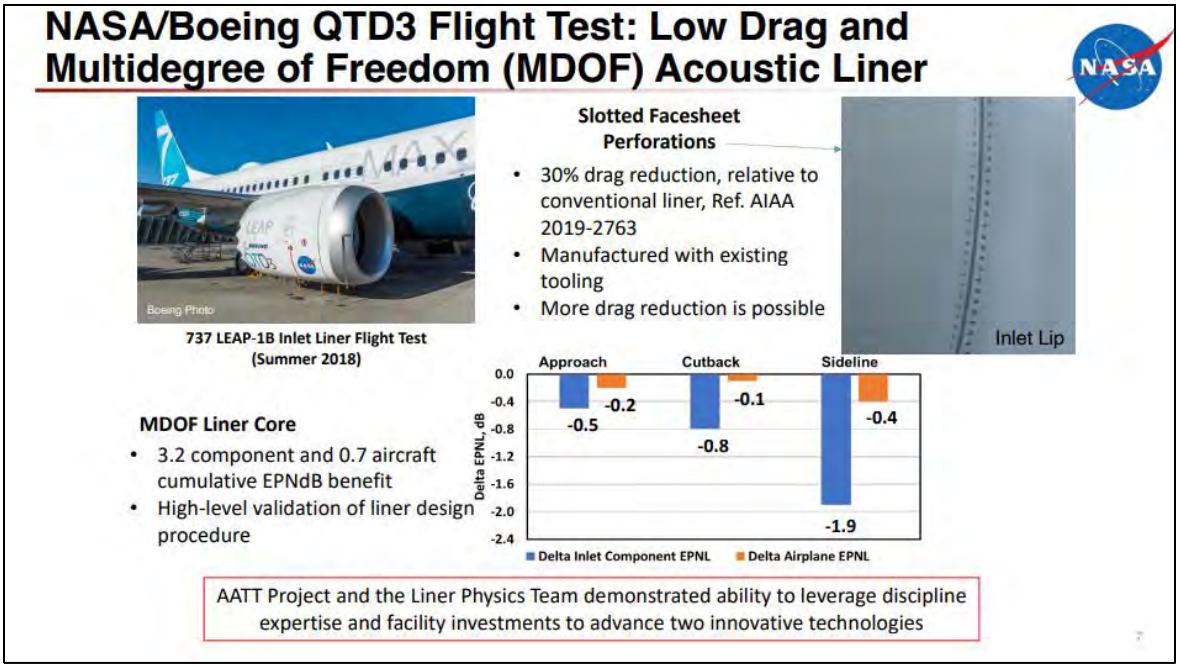

Figure 8.4-3 *Testing acoustic liner technologies in flight*

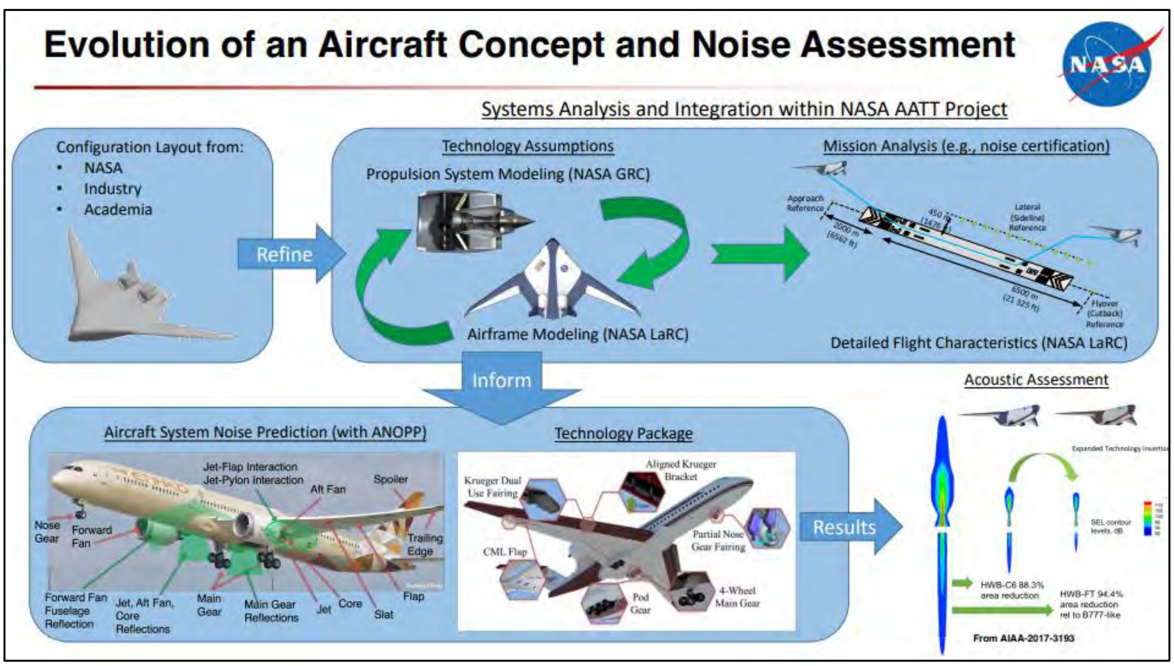

Figure 8.4-4 *Process for developing an aircraft concept and assessing noise*

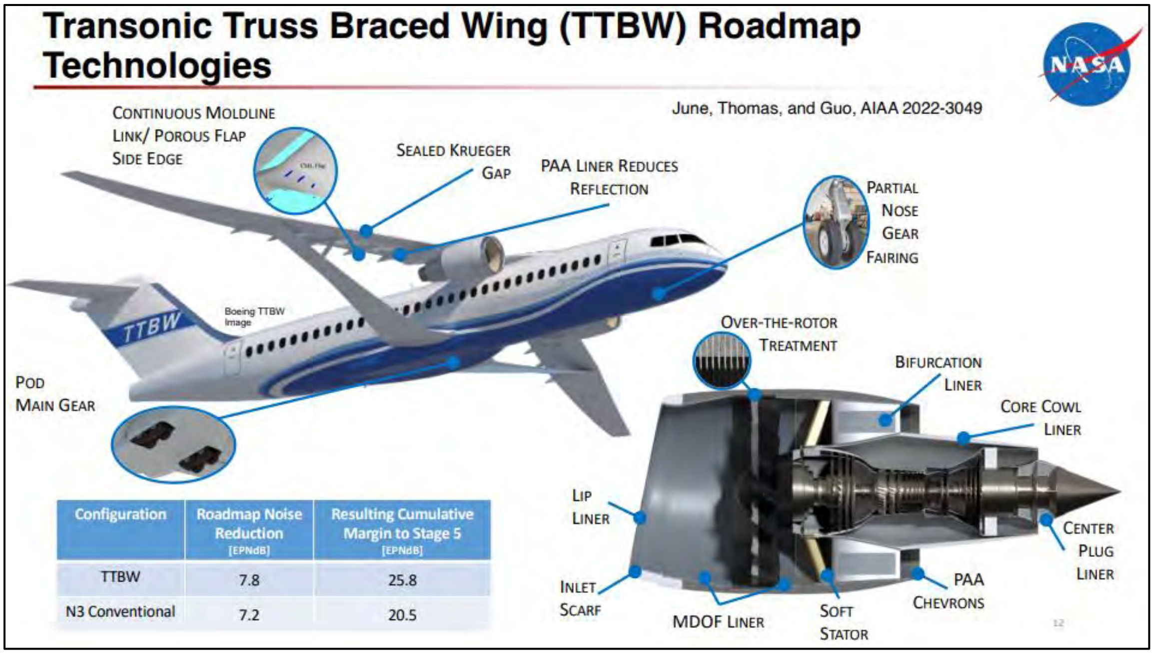

Figure 8.4-5 *Promising configuration: Transonic truss braced wing*

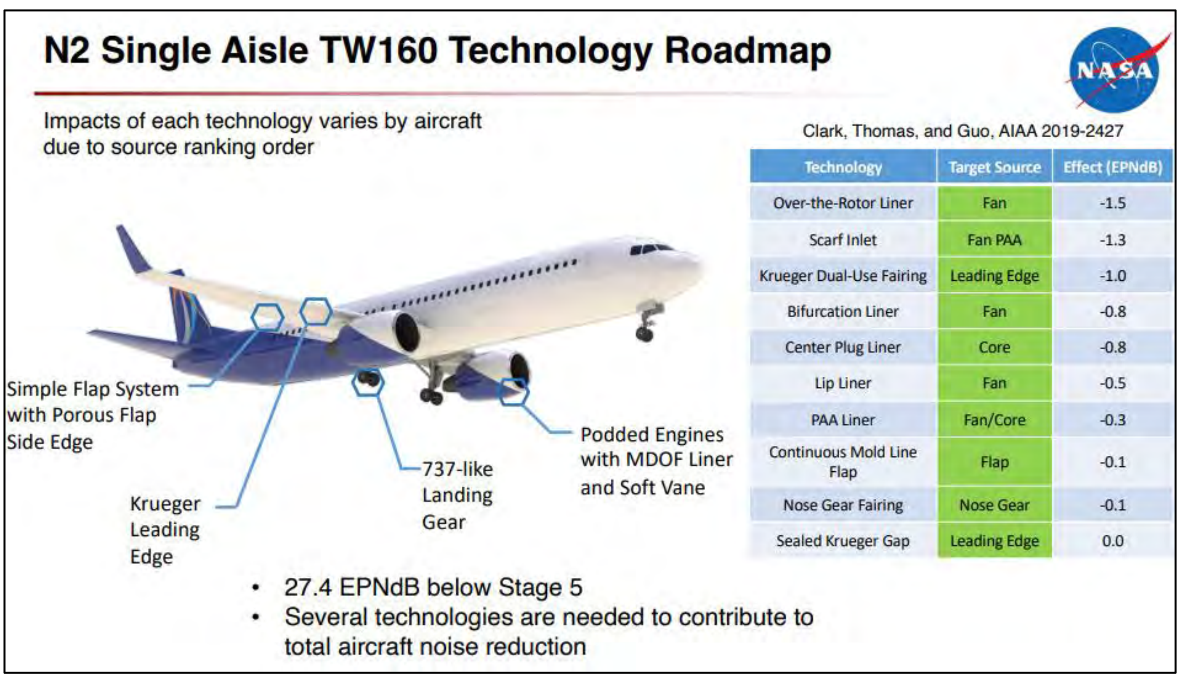

Figure 8.4-6 *Technology roadmap for more advanced N2 single-aisle aircraft*

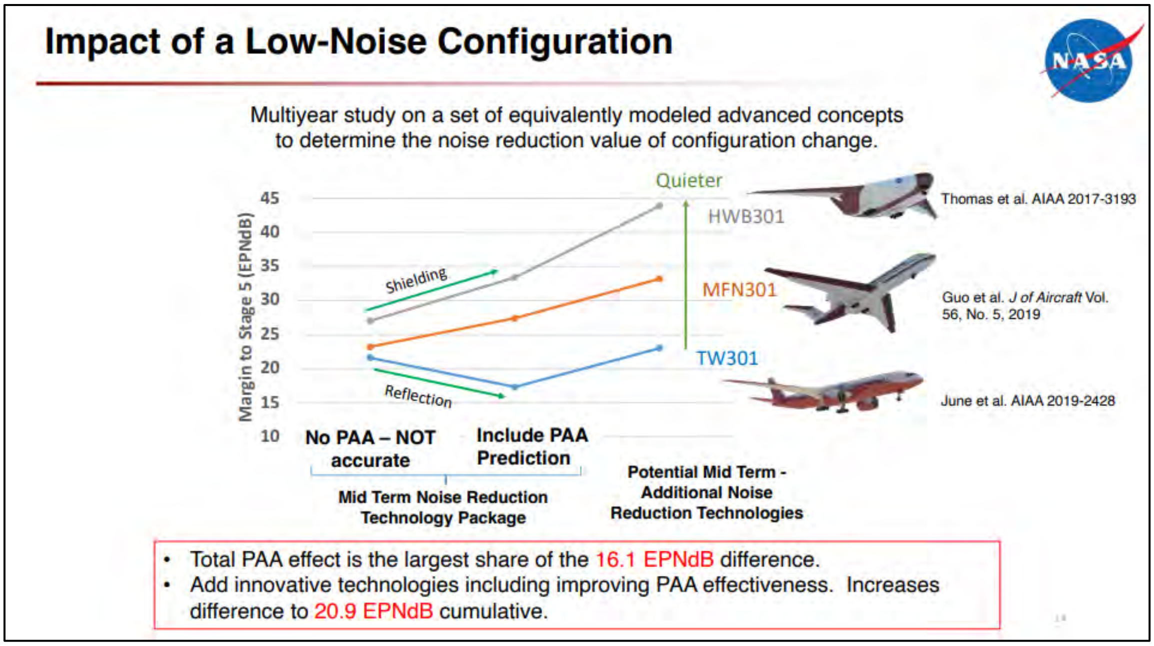

Figure 8.4-7 *Three configurations' cumulative noise impact*

Summary – To Implement More Noise Reduction Technology

- Must increase the available portfolio of feasible noise reduction technology:
  - Supports the setting of lower regulatory noise levels
  - More likely to be proactively implemented by industry
- Emphasize:
  - Robust discovery portfolio
  - Focused development:
    - ❑ Feasibility
    - ❑ Neutral to favorable weight, fuel burn, and other impacts
    - ❑ Less complexity
  - Flight/engine research:
    - ❑ Accelerates maturation (system integration and manufacturing proof-of-concept)
    - ❑ A key tool to explore and develop unique information and innovative approaches (e.g., 2020 NASA/Boeing PAA & ASN flight research on the 787 ecoDemonstrator)
    - ❑ Drives creativity

Optimistic on potential for innovative development of both technologies and operational approaches:

- ❑ Unique information and experience with innovative approaches
- ❑ Key new prediction methods in place
- ❑ Need well-structured collaborations between NASA and industry

Figure 8.4-8 *Priority areas to implement more noise reduction technology*

8.5 Activities of the Transportation Research Board's Airport Cooperative Research Program

Joseph Navarrete—Transportation Research Board of the National Academies of Sciences, Engineering, and Medicine

The Airport Cooperative Research Program (ACRP) is a program within the National Academies of Sciences, Engineering, and Medicine that conducts research to help airports operate more safely, efficiently, and responsibly. Environmental topics including noise are popular focus areas of ACRP research, and "Noise Around Airports" workshop attendees are encouraged to lend their expertise to the program—by participating on volunteer panels to guide research, for example, or proposing research ideas .

Joseph Navarrete, a senior program officer with the Airport Cooperative Research Program (ACRP) within the National Academies of Sciences, Engineering, and Medicine's Transportation Research Board, introduced workshop attendees to the ACRP, describing the program's mission, the types of research it undertakes, and ways to contribute to its research projects.

Although ACRP's research is evidence-based and unbiased, it is distinguished from traditional National Academies studies in various respects, including its audience of airport industry practitioners, and that its reliance on contractors to undertake the research. Some of the program's research is directed at providing guides and creating, and improving upon, existing models and tools.

Characteristics of the ACRP and its research efforts are summarized in Figure 8.5-1. Among these, the program operates in compliance with the Federal Advisory Committee Act, and does not undertake policy or regulatory research.

The ACRP produces guides for airport industry members that are designed to help airports with wide-ranging issues such as incorporating emerging technology, responding to an evolving regulatory landscape, and meeting customer expectations. The program also produces digests to help airports navigate legal issues, as well as syntheses offering snapshots of various airports' current practices. Online, the ACRP offers resources such as training videos.

The program has begun to conduct in-person "Insight Events" to nurture communication, collaboration, and innovation. These events have proved useful in supporting industry's understanding of emerging issues and promptly identifying relevant research needs. Recent issues have included the future of aviation, blockchain technology, and addressing systemic racism in the airport industry. A few years ago, an Insight Event was focused on land use compatibility and touched on noise issues.

Environmental topics, which include noise, are among the most popular subjects with ACRP's audience. Figure 8.5-2 lists ACRP noise-related research, which has included studies on improving noise models, collecting noise data, and managing community issues.

ACRP AIRPORT COOPERATIVE RESEARCH PROGRAM

Four studies help exemplify the program’s noise-related research:

- *Assessing Community Annoyance with Helicopter Noise*.

This study relied on a rigorous survey method, looking at three communities and with more than 2,000 respondents, to better understand the noise impacts of helicopter activity. The research team was able to correlate responses with estimates of DNL solely from helicopter activity. There was no apparent statistically significant difference between community annoyance from rotary-wing aircraft compared to that from fixed-wing aircraft. It was noted that helicopters around the communities studied were lighter civilian helicopters, and interest remains in studying noise impacts from heavier helicopters such as those on military bases.

- *Commercial Space Operations Noise and Sonic Boom Measurements*.

This study focused on an area that lacks robust data: far-field noise from commercial space operations. Data from launches of various sizes of rockets were collected. Observations from four successful launches were made over a year and a half. More than 250 acoustic recordings were collected from 70 sites, with distance from the launch site ranging from 0.2 kilometers to 27 kilometers. Still, more data are needed to improve the understanding of community noise impacts from these commercial space vehicles.

- *Evaluating the Use of Spatially Precise Diurnal Population Data in Aviation Noise Studies.*

This research looked at whether, and how, the accuracy of noise impact assessment could be improved by considering people’s locations and activities, which change over the course of each day. This examination was made possible by advancements in datasets and computational power. Researchers examined available datasets in terms of availability, quality, applicability, and compatibility (ease of converting the datasets for use with existing noise models). The team found that, while spatiotemporal data can enhance the understanding of noise impacts to some degree, limitations exist—for example, the data does not include information on the activities undertaken by the subject population—and more research is needed.

- *Primer and Framework for Considering an Airport Noise and Operations Monitoring System (NOMS)*.

This study supported development of a guide to help airports and communities evaluate the benefits and costs of an airport noise and operations monitoring system. The research relied extensively on surveys, case studies, and interviews with airports and vendors that did and did not have these kinds of systems. The research led to a decision-making flowchart to help airports evaluate the benefits and costs of acquiring, operating, and maintaining the NOMS, as well as guides for installing and maintaining the systems and for developing a noise management program.

The hope is that workshop participants would be inspired by these research examples to become involved with the ACRP. Ways to participate include serving on a project panel; submitting a research idea (called a "problem statement"); responding to requests for information from the program's research contractors; and conducting funded research.

Looking more closely at participation on a project panel, these panels of volunteers flesh out problem statements into requests for proposals specifying research objectives and desired products. They also select research contractors from submitted proposals, review interim deliverables, and provide guidance to the contractors. A workshop attendee who had participated in project panels noted that serving on a project panel is a great way to give back to industry, work with your peers, be on the cutting edge of research, and network. ACRP also covers travel expenses for panel members. Calls for panel nominations start in August each year and end around mid-September. Panelists generally come from the United States and sometimes Canada, given challenges such as tight travel budgets and time zone differences. Researchers, however, are considered from around the world.

In terms of submitting problem statements, the ACRP funds research that is applicable, achievable, implementable, and understandable, as described briefly in Figure 8.5-3. The goal of the research is to provide direct benefits to airports, so the ACRP is much more likely to fund research to help airports understand and reduce noise from their operations than research designed to improve aircraft design for noise reduction.

Examples of successful studies include research that led to guidance for airports looking to optimize their stormwater management, and in the area of noise, research into which products and methods work best for sound insulation of homes.

ACRP's problem statement submission information can be found at https://trb.org/ACRP/problemstatements. To stay up-to-date on opportunities with the ACRP, subscribe to the program's listserv by sending an email to LISTSERV@LSW.NAS.EDU. To find ACRP products, visit the program's website and use the search feature.

Figure 5.4-1 *Description of the Airport Cooperative Research Program*

Noise-Related Research

Project	Title	Date
02-05	Report 15: Aircraft Noise: A Toolkit for Managing Community Expectations	2009
02-09	Web-Only Document 11: A Comprehensive Development Plan for a Multimodal Noise and Emissions Model	2010
02-12	Report 86: Environmental Optimization of Aircraft Departures: Fuel Burn, Emissions, and Noise	2013
02-24	Report 105: Guidelines for Airport Sound Insulation Programs	2014
02-27	Web-Only Document 9: Enhanced Modeling of Aircraft Taxiway Noise	2013
02-26	Web-Only Document 16: Assessing Aircraft Noise Conditions Affecting Student Learning	2014
02-27	Web-Only Documents 9: Enhanced Modeling of Aircraft Taxi Noise	2013
02-31	Report 105: Guidelines for Ensuring Longevity in Airport Sound Insulation Programs	2014
02-35	Web-Only Document 17: Research Methods for Understanding Aircraft Noise Annoyances and Sleep Disturbance	2014
02-37	Web-Only Document 19: Integrated Noise Model Accuracy for General Aviation Aircraft	2014
02-44	Research Results Digest 24: Guidance for Helicopter Community Noise Prediction	2015
02-47	Web-Only Document 34: Assessing Aircraft Noise Conditions Affecting Student Achievement—Case Studies	2017
02-48	Research Report 181: Assessing Community Annoyance of Helicopter Noise	2017
02-51	Research Report 152: Evaluating Methods for Determining Interior Noise Levels Used in Airport Sound Insulation Programs	2016
02-52	Web-Only Document 32: Improving AEDT Noise Modeling of Mixed Ground Surfaces	2017

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Noise-Related Research (Cont'd)

Project	Title	Date
02-66	Web-Only Document 33: Commercial Space Operations Noise and Sonic Boom Modeling and Analysis	2018
02-79	Web-Only Document 43: Improving AEDT Modeling for Aircraft Noise Reflection and Diffraction from Terrain and Manmade Structures	2019
02-81	Web-Only Document 47: Commercial Space Operations Noise and Sonic Boom Measurements	2020
02-84	Web-Only Document 48: Evaluating the Use of Spatially Precise Diurnal Population Data in Aviation Noise Studies	2020
02-89	Research Report 237: Primer and Framework for Considering an Airport Noise and Operations Monitoring System	2022

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Figure 5.4-2 *Noise-related research at the ACRP*

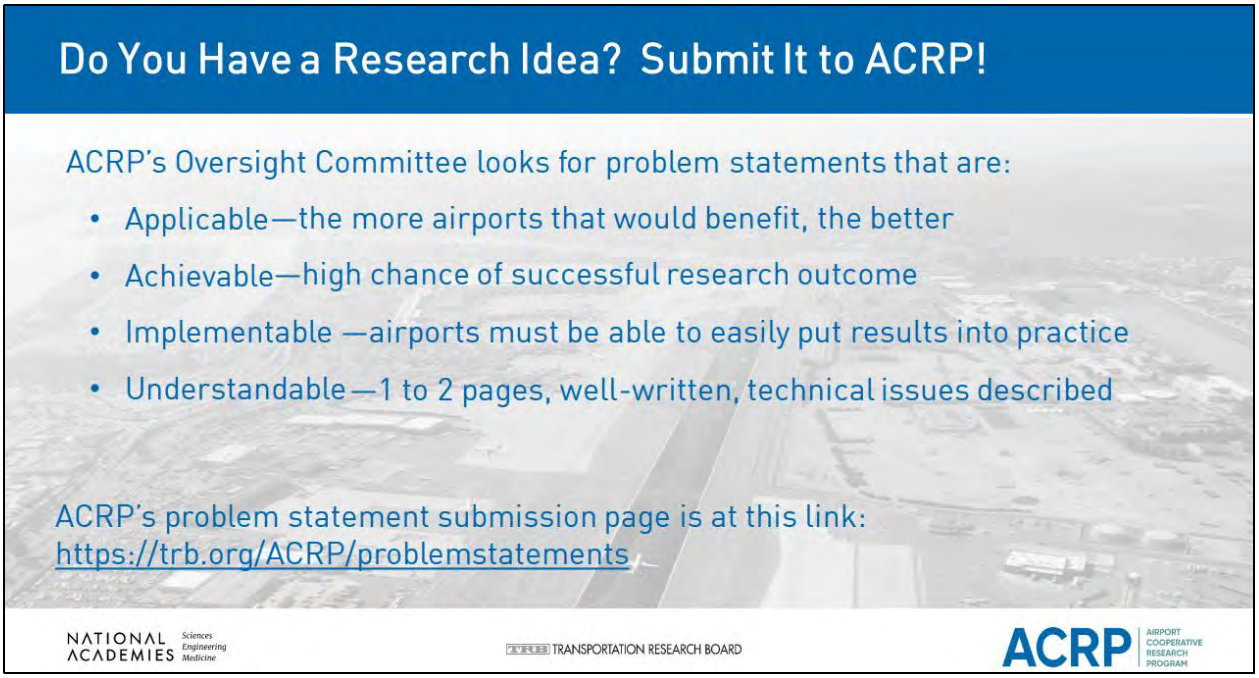

Figure 5.4-3 *Characteristics of ACRP-funded research projects*

8.6 The Impact of New Technology on the Future of Noise Around Airports

Ben Murphy—Boom Supersonic

Boom Supersonic has developed the Overture supersonic aircraft to offer high-speed flights to passengers while expecting to meet the ICAO Chapter 14 noise levels using advanced procedures. The technological innovations developed to achieve this feat of noise reduction are expected to prove useful in subsonic, as well as supersonic, flight.

Ben Murphy, Boom Supersonic's vice president of sustainability and his company's representative on an International Civil Aviation Organization (ICAO) Committee on Aviation Environmental Protection working group, discussed new technologies' potential impact on airport noise. While his company addresses this issue of airport noise through the lens of its supersonic vehicle under development (Overture), many of the tools, methods, and technologies in this sphere are expected to be applicable to subsonic aviation, as well.

Boom Supersonic aims to shift the aviation paradigm through its first commercial product, the Overture airliner, which has about 65 to 80 seats and an accessible projected airfare. The presentation focused on Boom's design of the Overture aircraft to meet the Chapter 14 ICAO noise levels, which presents a "considerable challenge" for a supersonic aircraft.

Boom is meanwhile committed to net zero carbon, using 100 percent sustainable aviation fuel (SAF). The aircraft will use proven, certified technologies whenever possible, while also adding innovative technologies. Boom has designed its airplane to work with existing infrastructure such as current airports, runways, and gates, to ease integration into airport operations. While speed is central to Boom's mission as it creates a supersonic aircraft, safety and sustainability are top priorities as the company develops its speedier alternative to conventional flights.

Reducing landing and takeoff (LTO) noise from supersonic aircraft presents a challenge, due in large part to the "wave drag" phenomenon addressed in Figure 8.6-1. The image on the right is Boom's XB-1 supersonic demonstrator vehicle. In the image using computational fluid dynamic analysis at increasing Mach numbers, shock waves arise at each area change, with these shock waves creating drag.

Boom found that a slightly reduced bypass ratio engine can optimize efficiency by reducing drag. This approach highlights a dichotomy, however, between optimizing cruise performance and minimizing landing and takeoff noise, as a bypass ratio decrease to produce thrust at takeoff, for example, tends to increase jet noise as jet velocity is traded for mass flow.

As Boom Supersonic advanced the Overture from the conceptual design phase to preliminary design, it discovered a number of innovations related to cruise performance and Chapter 14 ICAO noise levels. As summarized in Figure 8.6-2, the noise reduction innovations can be broken down into three areas:

- *Leveraging the engine cycle.* This centers around ensuring that the engine's exhaust velocity remains subsonic throughout the takeoff procedure, to avoid the shock-cell noise associated with supersonic exhaust.

- *Using advanced procedures and a "variable noise reduction system."* The first component of this system is programmed lapse rate (PLR), an automatic thrust control system that reduces engine thrust at a certain point during takeoff to reduce jet noise. This comes with additional, high-lift configuration changes to achieve a safe climb without needing as much thrust. Pulling the throttle back and reducing jet velocities meaningfully reduces noise during takeoff. A critical enabling technology for these procedures is the automatic takeoff throttle control system (ATTCS), a system already in the FAA regulations that ensures safe operations when an engine failure is detected, by increasing the thrust of the remaining engine(s).

- *Incorporating noise reduction by design.* This involves looking at the integration of various components, such as ejectors, mixers, chevrons, and acoustic liners, to optimize noise reduction features for a unique engine cycle. The image on the right in Figure 8.6-2 is a Boom highly scalloped mixer design. Use of this feature trades in low-frequency sheer-layer noise for higher-frequency sheer-layer noise. Consideration has been given to this and other designs, and Boom has also conducted nozzle configuration studies and looked at airframe noise mitigation.

In combination with these three technology buckets, it is expected that the aircraft will be capable of achieving Chapter 14 noise levels. How does the company *know* this, given that the aircraft has not yet flown? Boom has conducted high-fidelity analysis, building an in-house landing and takeoff noise prediction tool with a very robust methodology. While the approach leverages many standard practices, it also allows the flexibility in how takeoff profile is optimized.

To help ensure correct noise prediction from the start, given the daunting programmatic cost of changing the design later, Boom pursued computational aeroacoustics for high-fidelity simulations. The image at the bottom left of Figure 8.6-3 represents use of a code called PowerFLOW (a lattice Boltzmann code) to analyze the landing gear and understand airframe noise. For jet noise, simulations form the CharLES, which is a large-eddy flow simulator, shown in the figure's bottom right image, was used for time-accurate nozzle computational fluid dynamics testing, to predict noise levels across the frequency spectrum.

As any computational tool is only as good as its calibration, the team conducted a large series of nozzle acoustic tests, represented in the image in the figure's upper right corner. These studies included testing of about a dozen configurations in narrow wind tunnels in France, and at a hot-jet test facility, to make sure thermal properties were properly considered.

In addition to nozzle testing, the Boom team conducted half-span airframe acoustic wind tunnel tests, using the airframe model cut in half for acoustic testing. The tests supported tools calibration and development of a holistic noise prediction tool, and contributed to a very high confidence in the aircraft design. Even with this level of confidence, uncertainty always remains, so Boom has maintained a margin to ensure a buffer exists for the certification flight stage.

An additional upside of supersonic flight is the reduced need for nighttime airport operations. More flights can be undertaken each day, and increased speed translates into flexibility for longer flights with departure and arrival times fitting conveniently within daytime hours.

Another clear consideration for supersonic aircraft is the issue of sonic booms. For Boom's part, the company is committed to avoiding sonic boom impacts over land. Overture's airline partners will maximize time over water, operating only subsonically over land at about Mach 0.94.

Boom's quest to avoid sonic booms that reach land covers secondary as well as primary booms. Secondary boom is a phenomenon referring to low rumbles sensed by communities that are separate from the primary boom. Figure 8.4-4 captures the Boom acoustic team's secondary boom modeling. The first diagonal line represents a primary boom. And compression waves are seen going up into the atmosphere, with reflections and refractions bouncing the primary boom back down to land and causing a series of secondary booms.

In conclusion, noise is a critical design driver for Overture. "We recognize that noise is an important consideration, and we're committed to being socially responsible as we reintroduce supersonic aviation. To do that, we redesigned the vehicle to achieve the Chapter 14 noise levels, by leveraging some key innovations that we hope will also benefit subsonic flight."

In response to an attendee's question, Murphy stated that Boom is working with NASA on sonic boom prediction and modeling, and is also working with the FAA's ASCENT Center of Excellence program.

Another participant asked about Boom's perspective on non-acoustic environmental factors such as developing a sustainable vehicle with sustainable fuels. Boom as a company is committed to 100 percent sustainable aviation fuel. "We think we can serve as a very important bridge to help cover the price premium of SAF and become price competitive while still achieving net zero carbon emissions." In its recent order for Overture aircraft, United Airlines committed to net zero carbon operation of the airliner. Meanwhile, Boom is working to better understand non-CO_2 impacts. In the stratosphere—at the altitude its aircraft will fly—it is too dry for contrail formation, so the climate impacts are expected to be lower in this regard.

In response to a final question, Murphy stated that Boom has not yet had the opportunity to focus on boom effects on the ocean ecosystem and wildlife.

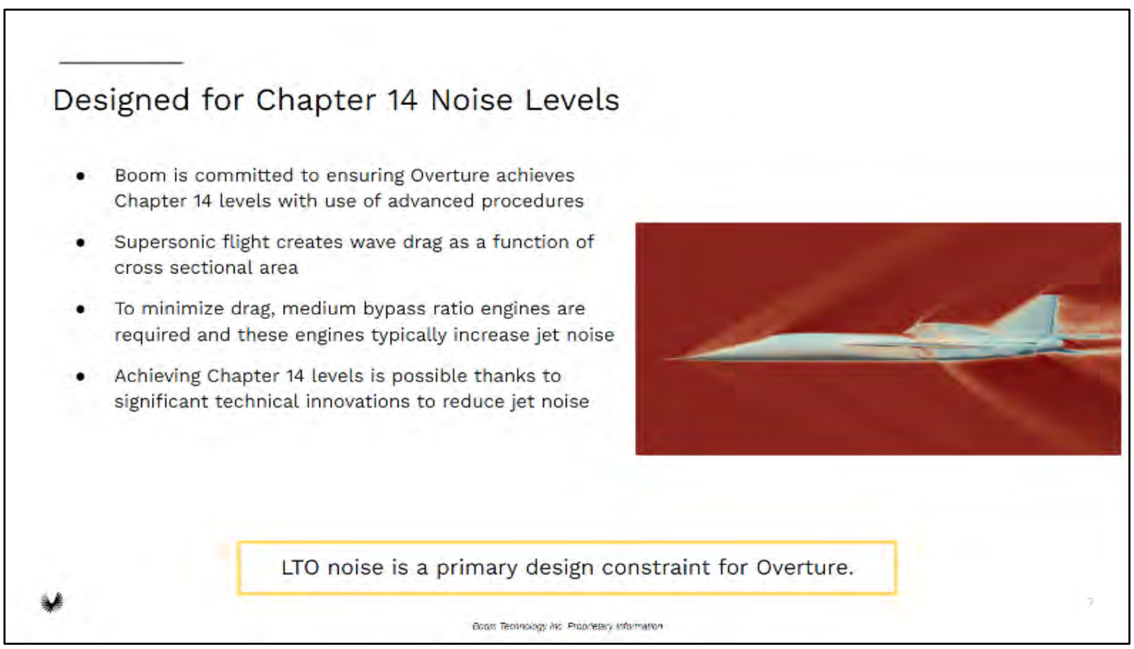

Figure 8.6-1 *Wave drag phenomenon is a challenge in reducing noise*

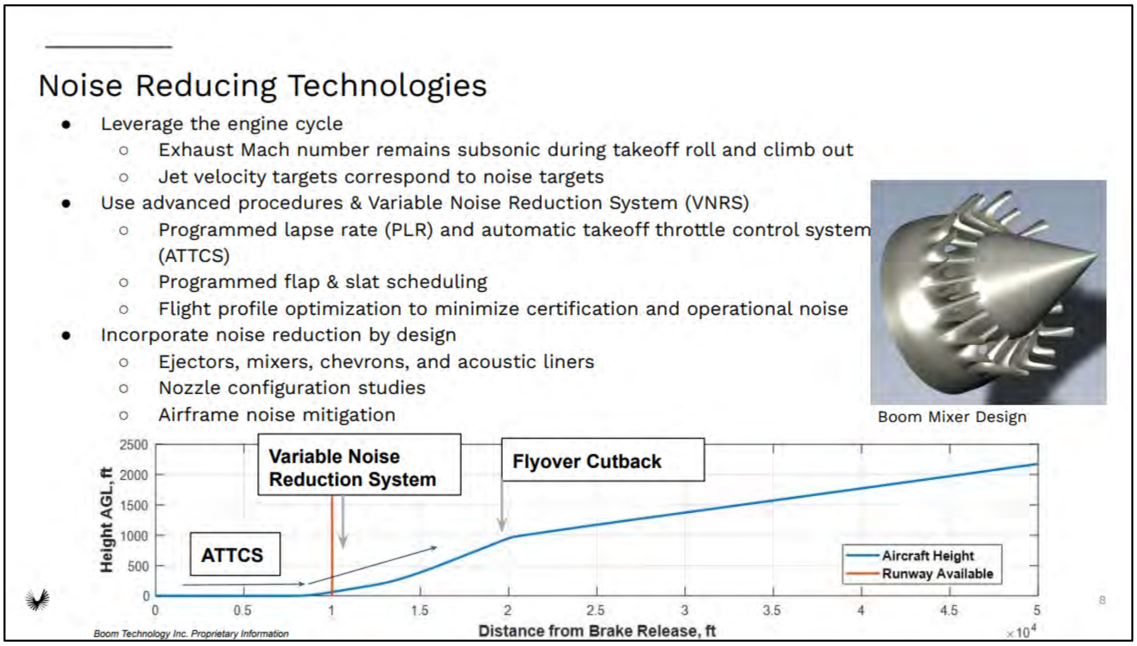

Figure 8.6-2 *Technological innovations for lowering noise levels*

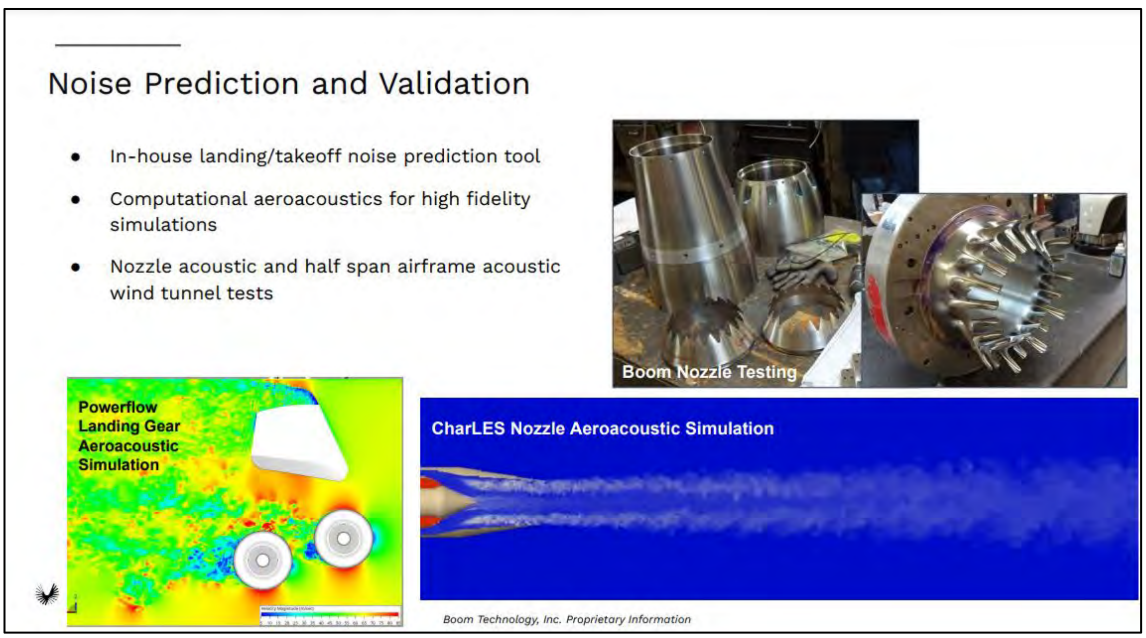

Figure 8.6-3 *Cutting-edge approaches to noise prediction and validation*

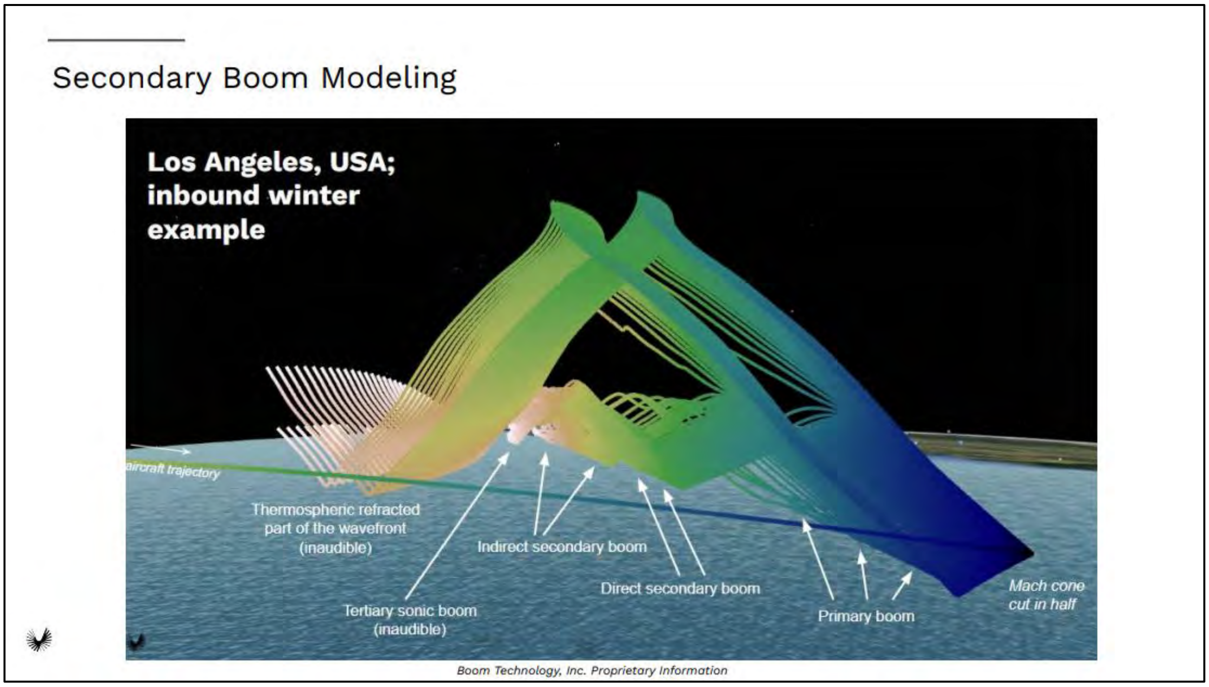

Figure 8.6-4 *Example of Boom's secondary boom modeling*

9 Workshop Closing

The final session of the workshop offered participants the opportunity for open discussion and feedback related to the presentations and the workshop overall.

The final session of the "Noise Around Airports: A Global Perspective" workshop offered attendees the chance for open discussion, feedback, and questions.

Eric Ducharme recognized the excellence of the workshop in terms of its global perspective and the speakers' specialized expertise covering a broad spectrum of viewpoints. Robert Hellweg echoed this praise and noted that there were more than 80 attendees representing 19 countries from Europe, Asia, Australia, South America, and North America. Hellweg praised the quality of the presentations and the thoughtful contributions of attendees through their related questions and discussion. Additional attendees likewise complimented the workshop for the exceptional exchange of ideas.

Ducharme stated that work must be continued in pursuit of a sustainable future for aviation, with noise as one of the most important considerations alongside emissions such as carbon dioxide that are becoming "an existential issue in this field." He highlighted the ICAO "Balanced Approach" discussed during the workshop, and how it could enable the reduction of noise at the source in aviation—not just from engines but from airplanes more generally. Ducharme also highlighted additional important areas of discussion from the workshop, including noise abatement through land use management, operating restrictions, and curfews and fees.

While acknowledging variations in approaches globally for addressing aviation-associated challenges including noise, Ducharme recognized a consistency in the framework around the world. It is important, he added, to bring out the contribution of the aviation industry, which has invested in quieter aircraft while retiring older, noisier planes.

Also important, according to Ducharme: the need, as emphasized during the workshop, to engage with airport communities in shaping policy. In achieving a reasoned regulatory approach, the societal benefits of aviation must be duly considered. Gregg Fleming echoed this perspective, stating that "the importance of the aviation industry to the global economic engine should not be understated." Among the benefits of global aviation: a contribution to "world peace," Ducharme stated, explaining that the chance to meet others in the world through travel can create empathy among people, and is an important part of the story of aviation along with safety and sustainability.

A workshop participant encouraged speakers to create an abstract of their presentations and submit them to INTER-NOISE and NOISE-CON conferences, to allow a wider audience to benefit from the information. Another participant reminded fellow attendees of the opportunity to submit ideas for their own research to the Airport Cooperative Research Program within the National Academies of Sciences, Engineering, and Medicine. On an administrative note, interest was expressed in accessing the complete sets of slides for TQA workshop presentations.

Patricia Davies raised the question of what steps could be taken to encourage effective community engagement in the aviation context by building on existing guidelines—some of which are already documented—to achieve a more systematic application of good practices. It would be helpful to create a framework for improving practices in this area, being mindful that practices may require tailoring based on each airport's circumstances.

Bill Lang and George Maling were warmly remembered for having inspired the important series of TQA workshops, among their many groundbreaking contributions to the field of noise control engineering. Workshop organizers expressed gratitude for the crucial support from the National Academy of Engineering, including the NAE's Sherri Hunter and Ahmir Robinson. They also extended their appreciation to the workshop's International Advisory Committee for identifying the best experts worldwide to participate in the workshop.

Appendix—A PROGRAM

Noise Around Airports: A Global Perspective

Virtual Workshop—November 1-4, 2022
Hosted by the International Institute of Noise Control Engineering
and the National Academy of Engineering

November 1—General—Community Response

8:30 **Introduction**: Adnan Akay, Sapienza University of Rome

Welcome: Alton Romig, NAE

8:50 **George Maling and William Lang contributions to the NAE Technology for a Quieter America consensus report and workshops**
Eric Wood, Acentech and Robert Hellweg, Hellweg Acoustics

9:10 Session 1

Keynote 1: **Global perspectives**
Gregg Fleming, U.S.DOT/Volpe Center

Noise situation at Australian airports
Marion Burgess, University of New South Wales

10:20 Break

10:30 Session 2

Noise situation at Brazil airports
Tânia Caldas, Ana Paula Gama, Jules G. Slama, and Julio B. Torres,
Federal University of Rio de Janeiro

Noise situation at Boston Logan Airport
Stephen Sulprizio and Flavio Leo, Massachusetts Port Authority

Departure sounds from jet aircraft: 1959—2011
Eric Wood, Acentech

12:10 **General Discussion**

12:30 **Day 1 ends**

November 2—General—Noise Situations Around Airports

8:30 **Introduction**: Eric Wood, Acentech

Welcome: Eric Ducharme, NAE

8:45 Session 3

Noise situation at Berlin Airport including noise protection program and single event noise fee
Ralf Wagner, Berlin Brandenburg Airport

Managing noise annoyance around Madrid Barajas Airport
Ana Garcia Sainz-Pardo, Eva Santos González, and Antonio Donoso López, SENASA

Noise situation at Dallas Fort Worth Airport
Sandra Lancaster, Dallas Fort Worth International Airport

10:15 Break

10:25 Session 4

Impact of cargo aircraft operations at Memphis Airport
Terry Blue, Memphis Shelby County Airport Authority

Noise situation at Hanscom Field, an airport primarily serving business jets
Amber Goodspeed, Massachusetts Port Authority

Keynote 2: Noise situation at West Coast US airports
Vincent Mestre, Consultant

12:05 **General Discussion**

12:30 **Day 2 ends**

November 3—Impact of Noise Around Airports

8:30 **Introduction:** Patricia Davies, Purdue University

Welcome: Robert Bernhard, I-INCE

8:45 Session 5

Keynote 3: Challenges and strategies for increasing community acceptance of aircraft noise in Japan: past, present and future
Naoaki Shinohara, Aviation Environment Research Center, Organization of Airport Facilitation, and Makoto Morinaga, Kanagawa University

Aviation noise is not only an engineering business
Laurent Leylekian, ONERA

Working with communities around airports when planning for changes
Charlotte Clark, St. George's University of London

10:25 Break

10:35 Session 6

Issues affecting results of noise surveys around airports
Truls Gjestland, SINTEF

Updates on FAA and the Neighborhood Noise Survey
Adam Scholten and Donald Scata, US Federal Aviation Authority

Liability of airports in the USA for noise impacts
Peter Kirsch, Kaplan Kirsch & Rockwell

12:05 **General Discussion**

12:30 **Day 3 ends**

November 4—Technology Considerations

8:30 **Introduction**: Gregg Fleming, U.S.DOT/Volpe Center

Welcome: Guru Madhavan, NAE

8:45 Session 7

Keynote 4: Noise metrics for airspace redesign—A UK perspective
Darren Rhodes, UK Civil Aviation Authority

Some lessons from Quiet Drones 2022 eSymposium
Jean Tourret and Dick Bowdler, INCE/Europe, and Phillippe Strauss CidB

Urban Air Mobility: Vertidrome and public acceptance research at the German Aerospace Center
Karolin Schweiger and Maria Stolz, DLR

10:25 Break

10:35 Session 8

Aircraft technology pathways to quieter and sustainable airports
Russell H. Thomas, Ian A. Clark, and Yueping Guo, NASA Langley Research Center

Activities of the Airport Cooperative Research Program, Transportation Research Board
Joseph Navarrete, Transportation Research Board, NASEM

The impact of new technology on the future of noise around airports
Ben Murphy, Boom Supersonic

12:00 **General Discussion and Closing Remarks**

12:40 **Workshop ends**

Appendix B

WORKSHOP ATTENDANCE LIST

Noise Around Airports: A Global Perspective

November 1-4, 2022

Aalmoes, Roalt
Royal Netherlands Aeropspace Center,
The Netherlands

Akay, Adnan
Sapienza University, Italy

Bernhard, Robert
University of Notre Dame and I-INCE, US

Bissegger, Martin
Zurich Airport, Switzerland

Blue, Terry
Memphis-Shelby County Airport Authority, US

Bowdler, Dick
INCE Europe

Brink, Mark
Federal Office for the Environment, Switzerland

Bultemeier, Eric
Boeing, US

Burgess, Marion
University New South Wales, Australia

Caldas, Tânia C. M.
Federal University of Rio de Janeiro, Brazil

Christian, Andrew
NASA Langley Research Center, US

Clark, Ian
NASA Langley Research Center, US

Clark, Charlotte
St George's, University of London, UK

Czech, Michael
Boeing, US

Davies, Patricia
Purdue University and I-INCE, US

Ducharme, Eric
NAE, US

Erdol, Muhammet
TUBITAK Marmara Research Center, Turkey

Fleming, Gregg
U.S.DOT/Volpe Center, US

Gama, Ana Paula
Federal University of Rio de Janeiro, Brazil

Garcia Sainz Pardo, Ana
SENASA, Spain

Geyer, Thomas
German Aerospace Center (DLR), Germany

Ghelberg, Stelian
Ministry of Environmental Protection, Israel

Gjestland, Truls
SINTEF Digital, Norway

Goodspeed, Amber
Massachusetts Port Authority, US

Guo, Yueping
NASA Langley Research Center, US

Hamamci, Samet Feyyaz
TUBITAK, Turkey

Hauge, Leo
SINTEF Digital, Norway

Hellweg, Robert
Hellweg Acoustics, US

Hesedahl, Jeanette
CENSEO AV+Acoustics, US

Hutcheson, Florence
NASA Langley Research Center, US

Jagniatinskis, Aleksandras
Vilnius Gediminas Technical University, Lithuania

Jones, Jeremy
Analytical Mechanics Associates, US

June, Jason
NASA Langley Research Center, US

Kirsch, Peter
Kaplan Kirsch & Rockwell, US

Köstli, Kornel
Federal Office for the Environment, Switzerland

Kurra, Selma
Turkish Acoustical Society, Turkey

Lancaster, Sandra
Dallas Fort Worth International Airport, US

Lang, Robert
IBM, US

Leo, Flavio
Massachusetts Port Authority, US

Leylekian, Laurent
ONERA, France

Loubeau, Alexandra
NASA Langley Research Center, US

Maling, Jeff
US

Maling, Norah
US

Meili, Peter
Zurich Airport, Switzerland

Mestre, Vincent
Consultant, US

Mickaitis, Marius
Vilnius Gediminas Technical University, Lithuania

Mitchell, Steve
Mitchell Environmental Ltd., UK

Morinaga, Makoto
Kanagawa University, Japan

Murphy, Ben
Boom Supersonic, US

Myyryläinen, Pasi
Akukon Oy, Finland

Navarrete, Joseph
ACRP/TRB, NAS, US

Nordenberg, Tamar
Vie Communications, US

Porter, Nicole
Anderson Acoustics, UK

Rhodes, Darren
UK Civil Aviation Authority, UK

Rizzi, Stephen
NASA Langley Research Center, US

Romig, Alton
NAE, US

Rönkkö, Manu
Akukon Oy, Finland

Sarı, Deniz
TÜBİTAK MAM, Turkey

Schiller, Noah
NASA Langley Research Center, US

Scholten, Adam
FAA, US

Schreckenberg, Dirk
ZEUS GmbH, Germany

Schweiger, Karolin
German Aerospace Center (DLR), Germany

Shelts, Kelly
NASA Langley Research Center, US

Shepherd, Kevin
NASA Langley Research Center, US

Shi, Tongyang
Institue of Acoustics, Chinese Academy of Sciences, China

Shinohara, Naoaki
Aviation Environment Research Center, Japan

Sparrow, Victor
Pennsylvania State University, US

Stolz, Maria
German Aerospace Center (DLR), Germany

Strauss, Philippe
French Center on Noise Information (CidB), France

Sulprizio, Stephen
Massachusetts Port Authority, US

Sun, Hyosung
Korea Environment Institute, Republic of Korea.

Tezel Oğuz, Melike Neşe,
TÜBİTAK MAM, Turkey

Thomas, Russell
NASA Langley Research Center, US

Thompson, James
JKT Enterprises, US

Torres, Julio Cesar Boscher
Federal University of Rio de Janeiro, Brazil

Tourret, Jean
INCE/Europe

Wagner, Ralf
Berlin Brandenburg Airport, Germany

Wahls, Rich
NASA ARMD, US

Wimmer, Mark
Massachusetts Port Authority, US

Wood, Eric
Acentech, US

Yamada, Ichiro
Organization of Airport Facilitation and Env. Improvement, Japan

Zaporozhets, Oleksandr
Institute of Aviation (ILot), Poland

NAE Support Staff

Hunter, Sherri
NAE Meetings Coordinator, US

Robinson, Ahmir
NAE Internet/Audio Visual, US

Appendix C

Acronyms and Definitions

AAD	Annual average day
AAM	Advanced aerial mobility
AATT	Advanced Air Transport Technology (NASA)
ACRP	Airport Cooperative Research Program
AEDT	Aviation Environmental Design Tool (FAA)
AIR	Aerospace Information Report (SAE)
AMS	Airspace Modernization Strategy (UK)
ANAC	National Civil Aviation Agency (Brazil)
ANEF	Australian Noise Exposure Forecast
ANCA	Airport Noise and Capacity Act (US)
ANCON	Civil Aircraft Noise Contour (UK)
ANIMA	Aviation Noise Impact Management Through Novel Approaches (EC project)
API	Application programming interface
APNL	Aircraft Noise Prevention Law (Japan)
APU	Auxiliary power units
ASA	Acoustical Society of America
ASN	Aircraft system noise
ANSI	American National Standards Institute
ASCENT	The Center of Excellence for Alternative Jet Fuels and Environment (FAA)
ASN	Aircraft system noise
ATTCS	Automatic takeoff throttle control system
BADA	Base of Aircraft Data
CAA	Civil Aviation Authority (UK)
CAEP	Committee on Aviation Environmental Protection (ICAO)
CEAS	Council of European Aerospace Societies
CFD	Computational fluid dynamics
CNEL	Community Noise Equivalent Level (California)
COD	Common Operations Database (ICAO)
CTL	Community tolerance level
DALY	Disability-adjusted life years (WHO guidelines for the European region)
dB	Decibel, a logarithmic unit of measurement in acoustics and electronics
dB(A)	Decibels, a unit for A-weighted sound level accounting for human perception of sounds at low-, mid-, and high frequencies
DENL	Day evening night level (with a 5 dB penalty for evening and 10 dB for night)
DFW	Dallas Fort Worth
DLR	German Aerospace Center
DNL	Day Night Level (a sound level metric that has a 10 dB penalty for night noise)
DOT	Department of Transportation (US)

EASA	European Union Aviation Safety Agency
EC	European Commission
ECAC	European Civil Aviation Conference
EPNdB	Decibels, a unit for EPNL which adjusts for tones in aircraft noise
EPNL	Effective Perceived Noise Level in dB (used in FAA certification of aircraft)
ESPR	Environmental Status and Planning Report
EU	European Union
eVTOL	Electric or hybrid electric VTOL
FAA	Federal Aviation Administration (US)
FICON	Federal Interagency Committee on Noise (US)
FOCUS	Forum on Complex Unifiable Systems
GERA	Airport Noise Study Group (Brazil)
HWB	Highbrid wing body
ICAO	International Civil Aviation Organization
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
ISO	International Standards Organization
iUSIM	Cross-institute, modular urban mobility simulation infrastructure (Germany)
LAeq	Equivalent sound level in dB(A)
LAeq,T	Equivalent sound level in dB(A) measured over a specified time T (instead of day or night levels) (UK)
Leq	Equivalent sound level in dB(A)
Lmax	Maximum sound pressure level in dB(A)
$L_A$max	Maximum A-weighted sound pressure level in dB(A)
LDEN	Day Evening Night Level (see DENL)
LDN	Day night level (see DNL)
LOAEL	Lowest observed adverse effect level (UK)
LTO	Landing and takeoff cycle
Massport	Massachusetts Port Authority
MIT	Massachusetts Institute of Technology
MOU	Memorandum of understanding
Nx or N_x	Sound level that is exceeded x% of the time
NADP	Noise abatement departure procedures
NA#	Number-of-events above # sound level
NAE	National Academy of Engineering
NASA	National Aeronautics and Space Administration (US)
NAT	Number above threshold
NEF	Noise exposure forecast
NES	Neighborhood Environmental Survey (FAA)
NOMS	Noise and Operations Monitoring System
OAG	Official Airline Guide
PAA	Propulsion airframe aeroacoustic
PBN	Performance-based navigation
PMVE	Property market value expertise

PRNAV	Precision Area navigation
RBAC	Civil Aviation Regulation (Brazil)
RNAV	Area navigation
RPM	Revolutions per minute
SAE	Society of Automotive Engineers
SAF	Sustainable aviation fuel
SEL	Sound exposure level in dB
SID	Standard instrument departure
SOAEL	Significant observed adverse effect level (UK)
STAPES	SysTem for AirPort noise Exposure Studies
TNO	Organization for Applied Scientific Research (Netherlands)
TQA	Technology for a Quieter America
TTBW	Transonic truss-braced wing
TW	Tube-and-wing aircraft
UAEL	Unacceptable adverse effect level (UK)
UAM	Urban air mobility
UAS	Unmanned aerial systems or unmanned aircraft systems
UK	United Kingdom
VR	Virtual reality
VTOL	Vertical takeoff and landing
WHO	World Health Organization
%HA	Percent highly annoyed

Noise Around Airports: A Global Perspective

TECHNOLOGY FOR A QUIETER AMERICA

TQA

Engineering a Better Quality of Life