Engineering a Quieter America

Aerial Mobility: Noise Issues and Technology

A TQA Virtual Workshop
December 2-3, 2020

A workshop organized by

The INCE Foundation

in cooperation with NASA and FAA

hosted by

The National Academy of Engineering, Washington, DC

Tamar Nordenberg, rapporteur

edited by

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

INCE USA

Institute of Noise Control Engineering of the USA

Engineering a Quieter America

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Institute of Noise Control Engineering of the USA

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PREFACE

This document is the final report on a virtual workshop hosted by the National Academy of Engineering (NAE) in Washington, DC on December 2-3, 2020. It includes a summary of each presentation and images of selected slides shown at the meeting. The workshop, *Aerial Mobility: Noise Issues and Technology*, was organized by the INCE Foundation in cooperation with the National Aeronautics and Space Administration (NASA) and the Federal Aviation Administration (FAA). The organizing committee consisted of Adnan Akay, Provost of Bilkent University, Gregg G. Fleming, Volpe Transportation Systems Center, Robert D. Hellweg, Hellweg Acoustics, George C. Maling, Jr., Member, NAE, and Eric W. Wood, Acentech Incorporated.

The workshop program is shown in Appendix A, and the list of registrants is shown in Appendix B. The *Technology for a Quieter America* (TQA)† NAE report published by the National Academies Press in 2010 did not cover noise from aerial mobility vehicles because they were not an issue at the time. That report covered NASA technology goals for America as well as European noise technology. It also contained recommendations for action by NASA and FAA.

At the virtual workshop on which this report is based, two officers from the NAE provided presentations. Several representatives from NASA gave overviews of activity on aerial mobility vehicle noise. Presentations were made by representatives from FAA and Volpe. Industry was represented by four presenters. Universities and consulting firms also had presentations. A lawyer addressed legal preemption and aerial mobility noise concerns.

ACKNOWLEDGMENTS

The NAE's support in hosting the workshop is very much appreciated. Special thanks to NAE Meetings Coordinator Sherri Hunter and meetings staff Dempsey Price and Mario Velasquez.

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

The editors, George Maling, Adnan Akay, Robert Hellweg, Gregg Fleming, and Eric Wood put in many hours in the preparation of this report, and are grateful to the authors of all of the papers for their presentations at the workshop and for reviewing the 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*, chaired by George Maling, which produced the 2010 NAE TQA report with its numerous findings and recommendations.

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EXECUTIVE SUMMARY

The purpose of the December 2020 workshop was to examine several facets of the increasing interest in air mobility vehicles. Air mobility is the preferred term for what was previously referred to as urban air mobility; the reason being that there are many vehicles used outside of urban areas and the term aerial mobility vehicle is a much broader term.

Two publications were issued shortly before the meeting, which influenced the direction of the presentations.

First, in mid-2020 the National Academies of Science, Engineering and Medicine issued a consensus study report *Advancing Aerial Mobility: A New Blueprint*. The document covered all areas of air mobility, but the one of most interest in the workshop is the demonstrated importance of public acceptance.

Second, in October 2020, NASA published a white paper, prepared by the Urban Air Mobility Noise Working Group, *Urban Air Mobility Noise: Current Practice, Gaps, and Recommendations*.

Both of these reports were addressed in workshop presentations – the National Academies report by Nicholas Lappos and the NASA white paper by Stephen Rizzi.

Nicholas Lappos from Lockheed Martin was the chair of the committee that produced the National Academies' consensus study report discussed above. He pointed out in his keynote presentation that environmental responsibility is central to the vision for advanced aerial mobility, and is important for noise as well as other environmental factors. He pointed out that in early 2020, 205 different aerial vehicles were in development and suggested that perhaps only 20 or 50 would survive. He said that it may take 15 years to see the report's vision through. "We have to start somewhere," he said. The following recommendation was made in the National Academies report:

Recommendation: Research should be performed to quantify and mitigate public annoyance due to noise, including psychoacoustic and health aspects, from different types of advanced aerial mobility operations. NASA should facilitate a collaboration between relevant government agencies--including FAA, Department of Defense, National Institutes of Health, academia, state and local governments, industry, original equipment manufacturers, operators, and nonprofit organizations--to prioritize and conduct the research with responsibility allocated per a coordinated plan and accountability for delivery incorporated. The research should be completed in two years. (Chapter 2).

Stephen Rizzi from NASA described the NASA urban air mobility working group study which was initiated in 2018 to produce the "white paper" mentioned above on urban air mobility noise. The working group had subgroups on ground and flight testing, human response and metrics, and regulation and policy. The result of the working group was the aforementioned NASA white paper published in October 2020 *Urban Air Mobility Noise: Current Practice, Gaps, and Recommendations*.

Some of the recommendations from the NASA white paper were:

- **Further development of system noise projection tools.**
- **Validation of prediction models for the highest amplitude noise sources.**
- **Continued development of auralization tools.**
- **Development of new measurement approaches in collaboration with various stakeholders.**
- **Development of standardized procedures for measuring and cataloging ambient noise.**
- **Perform laboratory studies to help inform how different the annoyance to short-term exposure to UAM is from existing aircraft.**
- **Develop models for audibility, noticeability, and annoyance to UAM aircraft noise. Study above differences in perception of UAM vehicle noise between communities.**
- **Collaboration with FAA and other agencies on standards for UAM noise.**

John Anderson welcomed the delegates to the workshop on the first day and pointed out that the topic of noise played a major role in the development of a rigorous review process for the NAE. There was a study done on the noise from supersonic aircraft in the 1960s, and the conclusions were not properly reviewed. As a result, the review process was greatly strengthened.

Al Romig, the NAE executive officer, welcomed the participants on the second day of the workshop. Before his appointment at the NAE, he served as general manager of Lockheed Martin's Skunk Works. With regard to the design of NASA's X-59 supersonic aircraft, Romig said that building the aircraft and flying it is step one. Step two is to send in the psychologists and sociologists to measure population’s reaction. He said that a similar approach to designing and acceptance of noise could be used for aerial mobility vehicles.

The second keynote speaker was Jean Tourret, INCE/Europe President, who spoke about the 2020 Quiet Drones virtual Quiet Drones e-symposium, which was organized in Europe on October 19-20, 2020. The symposium attracted 80 abstracts and was attended by 170 delegates from 22 countries. A proceedings book with forty-six papers was published with more than 500 pages. One topic covered was the situation with regard to regulation in Europe. The European Commission's Directorate-General for Mobility and Transport discussed the EU's regulatory framework for unmanned aircraft. There were other discussions on standardization and regulation by Robert Hellweg who discussed ANSI/ASA standards under development that are related to unmanned aerial system noise measurement. Michael Wieland with the UAV-DACH Unmanned Aviation Association discussed regulations for unmanned aircraft under European Regulation 2019/945.

Jean Tourret said that the Quiet Drones e-symposium confirmed that noise from drones is a broad, "hard and fast-developing" topic. He also discussed the low pace of noise-related regulation and used as an example wind turbine noise regulations that has been discussed for some two decades but has not been finalized in Europe or internationally.

Stephen Rizzi made a second presentation on the FAA Aviation Environmental Design Tool (AEDT) for conducting UAM fleet noise assessments. He said that presently AEDT is not fully equipped to handle UAM community noise studies, and he discussed many of the factors that must be added to make the AEDT useful for UAM studies. The results of these studies will be input to the AEDT database.

Stephen Alterman, President of the Cargo Airline Association also spoke at the workshop. One of the challenges he cited was improvement of environmental friendliness - including decreased noise - for cargo vehicles. Relatively small air mobility vehicles are another possibility for handling air freight, and therefore decreased noise is an important factor.

A portion of the workshop was devoted to regulatory issues and standards for the measurement of aerial mobility vehicles. James Hileman, the Chief Scientific and Technical Advisor for Environment and Energy at the Federal Aviation Administration (FAA), spoke about regulatory issues. Although the regulations for subsonic aircraft noise are well-defined, the question of helicopter noise is a somewhat different issue because generally people are troubled by helicopter noise at levels "far below" the levels of fixed-wing aircraft. Helicopter noise is a low frequency phenomenon that travels long distances. The sound sources are complex. However, helicopter noise and its measurement may serve as a guide for the regulation of aerial mobility vehicles. There is work going on both at the Department of Transportation (DOT) Volpe Center and at universities to define metrics for quantifying community noise from aerial mobility vehicles.

This work will complement the Aviation Environmental Design Tool (AEDT) described above by Rizzi. The FAA is working very closely with NASA and the Volpe Center and welcomes opportunities to collaborate with others in government, industry and academia.

A follow-on presentation by Donald Scata, also with the FAA Office of Environment and Energy, continued with the discussion of regulation of aerial mobility vehicles. The FAA considers factors such as the day-to-day operation, flight altitudes, flight speeds, appropriate metrics and methods of noise measurement in researching the best solution for certification. FAA is considering revisions to the regulations for fixed-wing aircraft in 14 CFR Part 36. Whether aerial mobility vehicles can fit within some of the categories already specified in the regulation remains to be seen and is an open question. While the current categories may cover some aerial mobility aircraft, new noise considerations are needed for a range of aerial mobility vehicles because of their unique noise characteristics and flight controls. There are many benefits to the FAA from other organizational partnerships and the agency is interested in fostering partnerships to collect environmental information, including noise data to improve the understanding of the acoustics of these aerial mobility aircraft and implications for their incorporation into the national airspace.

One organization dealing with standards for the measurements of the sound power emission from small unmanned aerial systems (UAS) is the Acoustical Society of America Accredited[1] Standards Committee S12 (Noise) Working Group 58. Led by Kevin Herreman of Owens Corning, this group has about 30 members and was created in 2016 to develop and maintain a new standard for the determination of sound power from small unmanned aerial systems. A draft standard for fixed-wing vehicles is expected by the end of 2021.

As discussed above, community acceptance is a key issue in the future development of aerial mobility vehicles. Mary Ellen Eagan, President of Harris Miller Miller & Hanson discussed the importance of effective communications strategies tailored for a range of stakeholders. She also spoke of noise metrics and noise modeling. Essential to the success of community acceptance is effective communication within each group, for example, manufacturers, operators, FAA officials, local governments, and the general public. She also spoke of noise metrics and pointed out that current metrics for example, the metric used for certification of aircraft, effective perceived noise level, and the metric used for assessment of annoyance around airports, the day-night average sound level, may not be sufficient for

[1] Accredited by American National Standards Institute

identifying problems with advanced air mobility vehicles. Conducting and funding research on annoyance from these vehicles is, she said, imperative.

This general theme of community acceptance was also considered by Mark Blanks, director of the Virginia Tech Mid-Atlantic Aviation Partnership. He spoke of a project to measure community acceptance of deliveries of packages to actual residences. Community reaction to the drone delivery service was overwhelmingly positive, breaking down as 86% positive, 13% neutral, and 1% negative. He summarized by saying that gaining the needed acceptance for these vehicles relies on maximizing the value to communities while ensuring that there is community acceptance. In addition, Blanks explained the noise mitigation used by the company based on its experience in Australia. The company took three major actions to manage noise from its operations: 1) locating its “nest,” or operations hub for takeoffs and landings, away from residential areas, 2) randomizing flight paths, with the aim of approaching from a different angle for repeated deliveries to the same place, and 3) designing aircraft with noise reduction in mind. He summarized by saying that gaining the needed acceptance for these vehicles relies on maximizing the value to communities while ensuring that there is community acceptance.

This issue of community acceptance was also covered by Javier Caina, Director of Technical Standards at DJI, one the largest manufacturer of small UAS vehicles. He raised the issue by saying that "is there really even a problem with the drone noise?". He said that there are many challenges with regards to drones, particularly in the European Union. However, he finished his presentation by saying that the development of regulatory approaches "seems indeed to be a solution in search of a problem."

Another presentation related to community acceptance was by Eddie Duncan and Kenneth Kaliski from RSG Corporation. The study focused on community acceptance through the design of optimized routes for delivery services. Looked at noise exposure of a population considering four flight routes-direct, roadway, waterway, and railway. Noise mapping, coupled with an analysis of routing options, was shown to represent a powerful tool for quantifying and reducing noise impacts from drone delivery services. However, to take advantage of the potential for routes over certain areas to provide a level of masking and reduce noise impacts, more and better information is needed on drone sound emissions.

David Read of the DOT Volpe Center reiterated the idea that public acceptance of aerial mobility aircraft will depend in a large part on effective management of noise. Aircraft noise certification is an important part of the process of determining community acceptance. Certification requires a noise metric, and he pointed out that noise metrics are different for different sources, for example, small propeller-driven fixed wing aircraft, small helicopters, and jets together with large propeller-driven airplanes, as well as large helicopters. He presented data on several typical sources.

He next presented Volpe's recommendations to support noise certification of aerial mobility vehicles. He said that noise from these aircraft may exhibit annoyance effects substantially different from what the public has previously experienced. He said that there is a lack of representative noise datasets, and when these datasets are available, the next step will be evaluation to determine whether any updates are needed to the existing noise certification paradigm.

John-Paul Clarke of the University of Texas covered operations and routing for air mobility vehicles. He said that trajectory optimization can play a key role within a toolkit for addressing community noise concerns associated with air mobility. Trajectory optimization can also play an important role in terms of efficiency, privacy, and safety. He said that rotorcraft noise can be reduced by optimizing arrival (descent) and departure (ascent) trajectories. Such trajectories can also be designed to increase the distance from a receiver and to keep trailing blades away from the wake of preceding blades, etc. He suggested that noise thresholds can be converted into 3D constraints. And these constraints can be converted to the equivalent of an acoustic terrain to determine optimization for a trajectory. In this way, noise within an acoustic terrain can be treated the same way as a physical terrain. He also suggested that geofences may be created to define areas where aircraft may not enter.

There were several papers at the workshop devoted to psychoacoustics. Judy Rochat of Cross-Spectrum Acoustics spoke about community impact, including perception, and particularly the spectral content of noise emissions. She said that spectrograms provide a visualization of prominent tones and gave several examples. Noise from aerial mobility vehicles is highly tonal and that affects community response. She pointed out that the existence of three or more harmonics can make a sound more alarming or urgent and contributes to the sound's harshness. She also discussed the question of flight corridors, and gave several ideas on how to minimize noise issues. For example, selection of a route that helps to shield noise from observers.

A number of psychoacoustics considerations was also presented by Andrew Christian, a researcher at NASA. The subject of his first presentation was the audibility of signals in noise. When the background noise is very high, there is little problem detecting when a sound is audible. On the other hand, as the sound is lowered and becomes partially masked by the background noise, audibility is hard to predict, and this was the area studied by Christian.

The second presentation by Christian relates to noise metrics. He discussed the tone-corrected perceived noise level (PNLT) which is a much more complicated metric than A-frequency weighting. The metric has its roots in the difference between perception of noise from propeller aircraft and noise from jet engines. Modern instrumentation makes this quantity easier to measure. He concluded that even more complex metrics may be required in the future for the use with aerial mobility vehicles.

Patricia Davies of Purdue University presented information on sound quality. Sound quality greatly influences a person's reaction to sounds and therefore its acceptability. Quantities such as spectral balance, tonalness, signal variations, impulsiveness, and harmoniousness are important characteristics of a signal that influence sound quality.
There has been progress in the standardization of sound quality measures, but there are still many outstanding challenges. We already have lots of measures for noise emissions, such as day-night average sound level (DNL). Davies said a challenge will be to incorporate some of the sound quality metrics into a metric such as DNL. A comment directly related to the noise emissions of unmanned aerial vehicles: it is important to listen to what people are saying about the vehicle noises and how they are described. Such information is useful in developing sound metrics and has an important role in vehicle sound optimization.

There were also several papers devoted to the design of air mobility vehicles. Brian Yutko, chief technologist with Boeing NeXT, talked about the first principles of design. Noise is much more than decibels. The physics of noise is one thing but, as we have seen and other presentations in the workshop, annoyance is complicated and subjective. His own perception of noise was illustrated in a helicopter flyover which he characterized as very annoying and intrusive but his work on an electric VTOL aircraft he said was much more random and much less annoying.

This same theme was discussed by Julien Caillet from Airbus Helicopters. His presentation was "From Helicopters to Quiet eVTOLs - a Manufacturer's Perspective on Noise." The noise of helicopters is well regulated by the International Civil Air Organization, Annex 16. He discussed design considerations for helicopters and identified rotor propeller design as a key noise level driver. The company's lessons learned about helicopter noise and its impact on communities can contribute importantly to the understanding of noise issues in advanced aerial mobility vehicles. He said that Airbus currently uses conventional metrics but that other metrics are being considered, and the research community is in a better position than manufacturers to develop such metrics.

A closely related topic is the work on reducing propeller and rotor noise from UAS as described by Philip Morris of the Penn State University. He described the work of a NATO organization research task group, AVT-314 on this subject. The research group has international participation from several NATO countries; Sweden (a non-NATO country) is also included. The group has met several times to discuss various aspects of UAS noise reduction. The focus of the research is on reducing propeller and rotor noise from UAS. A technical paper on the research is expected to be prepared by the end of 2021.

The final presentation in the workshop was given by Robert Kirk, a partner in the Washington, DC, law firm of Wilkinson Barker & Knauer. In analyzing noise issues, he suggested the "FRISCO" approach. **F**ederal **R**egulation, **I**ndustrial **S**afeguards standards, and **C**ommunity **O**utreach are key issues in the analysis of noise. He expanded on the FRISCO approach and again, highlighted the importance of public acceptance for industry's success. There must be coordination with state and local governments in the determination of community impacts, otherwise such governments attempt to enact airspace regulations even though they are precluded from directly regulating aerial mobility laws.

2

INTRODUCTION

Background

The 2010 NAE report *Technology for a Quieter America*[2] (TQA) emphasizes the importance of engineering to the quality of life in America, 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; the role of government, education, and public information in noise control; and a wide range of related recommendations. Implementation of recommendations in the report promise to reduce noise levels to which Americans are exposed and improve the ability of United States industry to compete in world markets where increasing attention is being paid to products' noise emissions.

Two reports published in the United States in 2020 have indicated that more efforts have to be made to understand the public acceptance of noise from air mobility vehicles., This includes aircraft as well as drones, and other air mobility vehicles such as air taxis and freight vehicles.

The first report was a consensus study by the National Academies of Science, Engineering, and Medicine *Advancing Aerial Mobility: A National Blueprint* [3]. The report covered air mobility vehicles and identified public acceptance as a major inhibitor to the future development of the field. It recommended a program to the National Aeronautics and Space Administration (NASA) to investigate the situation and determine, for example, if new metrics are needed for the evaluation of these vehicles.

The National Academies report recommended that:

> **Research should be performed to quantify and mitigate public annoyance due to noise, including psychoacoustic and health aspects, from different types of advanced aerial mobility operations. NASA should facilitate a collaboration between relevant government agencies—including FAA, Department of Defense, National Institutes of Health, academia, state and local governments, industry, original equipment manufacturers, operators, and nonprofit organizations—to prioritize and conduct the research, with responsibility allocated per a coordinated plan and accountability for delivery incorporated. The research should be completed in 2 years.**

The second report was a NASA "White Paper" Urban Air Mobility Noise: Current Practice, Gaps, and Recommendations which detailed a roadmap for future NASA activities concerning urban air mobility noise.

The National Academies and NASA reports are discussed in more detail in sections 6 (Lappos) and 8 (Rizzi) of this document.

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[2] https://www.nap.edu/download/12928

[3] https://www.nap.edu/catalog/25646/advancing-aerial-mobility-a-national-blueprint

Scope[4]

This report on a TQA follow-up workshop provides information on the many new and useful private, government, and commercial applications for aerial mobility vehicles. Operations near populated residential areas can be expected to introduce environmental sounds unwanted by the general public unless industry, responsible government agencies, and the engineering community plan for and implement steps to reduce noise emissions from these vehicles. During this workshop, experts from government, academe, and the private sector addressed noise from AMVs and public acceptance of these vehicles.

Workshop attendees expressed a common commitment to partnering with others in government, industry, and the public toward integrating drones into the national airspace.

Content

- Determination of sound power level of aerial mobility vehicles.
- Community acceptance of air mobility vehicles.
- Annoyance effect of air mobility vehicles.
- Certification and regulatory issues
- Psychoacoustic considerations and sound quality.
- Design of air mobility vehicles.
- NATO progress on research on noise from unmanned aircraft.
- Legal preemption and aerial mobility noise concerns.

This report includes a summary of findings based on workshop presentations. The workshop agenda, a list of the 71 workshop attendees, and a list of acronyms are provided as appendices.

A transcript of the entire workshop was prepared. Presenters were provided the opportunity to review and edit their portions of the transcript. A professional science writer was retained to attend the workshop and prepare draft presentation summaries based on the transcript and presenters' slides. The presenters then had the opportunity to review and edit the draft summaries of their presentations. Occasionally, presenters inserted post-workshop information to clarify and/or add insights. The TQA Editorial Committee reviewed and edited the presentation summaries to ensure accuracy and clarity, and then integrated the information in this report format.

Continuing dialogue is expected among workshop participants and additional interested parties. And future TQA follow-up workshops are expected during 2021 and beyond.

[4] https://ntrs.nasa.gov/search?q=20205007433

3. Opening Remarks

George C. Maling Jr.—*NAE*

George Maling opened the workshop on December 2, 2020. He said that this workshop is the eleventh in a series of workshops hosted by the National Academy of Engineering (NAE). The workshop was held on December 2-3, 2020. This series of NAE-hosted workshops has been held, since 2016, based on a new policy on member-initiated projects announced by the NAE in October of that year.

There were three significant events in the second half of 2020. First, there was a National Academies of Science, Engineering, and Medicine consensus report on aerial mobility titled *Advancing Aerial Mobility: A National Blueprint*. Noise played a major role in that report, as detailed in the executive summary and introduction to this report and in the summary of Nicholas Lassos' presentation. Second, there was a white paper produced by NASA which outlined NASA's future activities with regard to aerial mobility. That report is also covered in the executive summary and introduction, as well as in a summary of Stephen Rizzi's presentation in this report.

In October 2020 there was a virtual symposium "Quiet Drones" organized by INCE Europe with a proceeding containing more than 50 papers; the Quiet Drones e-symposium is described in the Jean Tourret summary in this report.

Maling then introduced John Anderson, president of the National Academy of Engineering (NAE), who welcomed attendees on behalf of the NAE.

NATIONAL ACADEMY OF ENGINEERING

4. Welcome From the National Academy of Engineering

John Anderson—*NAE*

John Anderson, president of the National Academy of Engineering, welcomed aerial mobility workshop attendees. He highlighted the Academy membership-inspired, NAE-sanctioned nature of this and other workshops in the "Engineering a Quieter America" series and expressed appreciation for the workshops' important benefits to the NAE.

Aerial mobility workshop welcoming remarks were provided by John Anderson, president of the National Academy of Engineering, which hosted this workshop as it did previous ones in the "Engineering a Quieter America" series. "We are proud to be a partner in this series of workshops," Anderson stated, pointing out that the topic of noise played a major role in the establishment of the National Academies' rigorous review process used to protect the integrity of the Academies' reports and workshop proceedings. The speaker went on to specify that the establishment of the Report Review Committee (RRC) grew from problematic, insufficiently reviewed conclusions in a 1968 National Academies report on the potential effects on building structures of sonic booms from proposed commercial supersonic transport (SST) aircraft. The report concluded that a single sonic boom did not present a problem, but failed to note that a series of sonic booms could weaken residential and business structures, sometimes causing collapse. It concluded that the probability of material damage from sonic booms generated by aircraft operating supersonically in a safe, normal manner was very small—a conclusion that was used, out of context, to support the development of SST commercial flights over the United States.

In response to this misleading report, the National Academies was compelled to issue a statement recognizing the sonic boom study's limitations. Also in response to these accuracy issues, the National Academies created the Report Review Committee. The RRC's crucial review layer bolsters the credibility of the Academies' work, Anderson stated, recognizing that some workshop participants may have served as reviewers of the Academies' consensus panel reports. "By doing so, you contribute greatly to the credibility of the National Academies' work, and I thank you for that," he said.

Consensus studies require rigorous review of conclusions to ensure the credibility of science and engineering in the eyes of the technical community, the public, and the government, Anderson stated. Importantly, he emphasized, technology-related issues that affect the public must be presented to the government and citizens alike in a nonpartisan way.

This series of TQA follow-up workshops—and this workshop, as a prime example—helps fulfill that mission, he said. Unmanned aerial vehicles present potential benefits and risks to the public, with noise at a level and persistence that presents a health risk as well as an inconvenience. Anderson stated, "We need your guidance to protect the public. I applaud George Maling and his colleagues for maintaining TQA's momentum. Your work has been, and will continue to be, important to all of us." The NAE president closed by thanking workshop organizers and attendees, and emphasizing the conference's promise for bringing important ideas to light.

NATIONAL ACADEMY OF ENGINEERING

5. Urban Mobility Noise: Psychology of Air Vehicle Noise

Alton Romig—NAE

Sophisticated projects in air vehicle development—even those unrelated to urban air mobility—can suggest effective strategies for designing and operating aerial mobility vehicles. One example is the Lockheed Martin experience building NASA's X-59 supersonic aircraft, which could possibly guide the evolution of urban mobility vehicle design and operations.

NAE executive officer Alton Romig presented brief comments on urban mobility vehicle noise within the broader context of air vehicle noise, focusing in particular on population reaction to, and acceptance of, sound from these vehicles. Having served earlier in his career as general manager of Lockheed Martin's Skunk Works, a pioneering program in aircraft design, Romig has expertise on air vehicle speed and stealth, he stated, pointing out the common concern over noise in the contexts of speed and rotary wing aircraft.

Focusing first on speed and sound, Romig explained that his colleagues at Skunk Works partnered with NASA to build NASA's X-59 supersonic aircraft, the design of which stretches out the shockwave of a sonic boom to achieve a thunder-like rumble rather than an intense sharp crack. Of studying the sound from aircraft such as this one, Romig said, "Building the aircraft and flying it is step one and step two, after which we will send in the psychologist and sociologist to measure population reaction."

Romig next posed the question, could a similar approach to considering design and sound acceptance be used for urban mobility? Important differences exist among vehicles, he said, which must be considered. For example, the sound from a small electric sport drone could be associated with 20 dBA to a listener on the ground, and a delivery drone also electrically powered might be 40 dBA. A four-to-six-person helicopter with a turbo shaft engine could be around 90 dBA — perhaps slightly less with the helicopter at 500 feet. These examples demonstrate the huge difference in sound from vehicle to vehicle, Romig pointed out, given loudness doubles with every 10 decibels. Highlighting that it is difficult to peg yet where urban mobility vehicles would fall on the spectrum—maybe 60 or 70 decibels, by Romig's educated guess—the noise would "certainly be enough to cause issues for the population in the area," he said.

The NASA X-59 strategy might be useful in this urban mobility context, he said: Build the vehicles and fly them, with a specific objective of learning about the general population's acceptance of the resulting sound. While shedding light on possible design modifications for minimizing the community's sound exposure, the approach could meanwhile influence additional factors involved with flight operations, such as flight profiles and landing site selection, that could also reduce the community's burden. Romig concluded his presentation by stating, "It would be nice to have all these questions answered before you actually put vehicles into a fleet."

6. Keynote Address: Advancing Aerial Mobility: A National Blueprint

Nicholas Lappos—Lockheed Martin and NASEM Committee on Enhancing Air Mobility

The U.S. aerial mobility industry's potential benefits and challenges were recently evaluated by a committee of experts from the National Academies of Sciences, Engineering, and Medicine in this emerging area. The resulting report, titled Advancing Aerial Mobility: A National Blueprint*, sets forth recommendations for developing and deploying technologies in support of a sophisticated—and publicly welcomed—aerial mobility system.*

Lockheed Martin's Nicholas Lappos served as chair of the committee that developed a National Academies of Sciences, Engineering, and Medicine (NASEM) report on *Advancing Aerial Mobility: A National Blueprint*[5] The consensus study report, which is available online, provides recommendations from the NASEM Committee on Enhancing Air Mobility, toward an evolved aerial mobility system of the future. The committee was tasked with developing a report discussing a national vision for urban air mobility; identifying key technical, economic, regulatory, and policy barriers for achieving the vision; and addressing additional factors important to achieving the vision for advancing aerial mobility. (See Figure 6-1.)

The group chose to update the "urban air mobility" terminology referenced at the outset of report development to "aerial mobility," to reflect the focus on not only urban environments but also suburban and rural ones, which Lappos emphasized, "are also ripe for connecting with each other using air mobility tools." NASA has likewise substituted the new term "aerial mobility," given the common benefits and challenges across types of regions.

Figure 6-2 highlights the committee's assumptions and guiding principles in developing the aerial mobility report. Social acceptance—and the influence of noise on this acceptance—was an important consideration for the committee. "Modern systems and modern technologies that allow people to communicate can be used to either foster the development of these systems or to counter them," he said, adding that noise plays an especially important role, "as a socially acceptable way to complain about something."

The committee recognized two perspectives on noise: the actual sound pressure level and the psychological perception. Some noise complaints are lodged where noise levels are objectively very low, according to committee members, and the psychological impact of intrusion in the form of noise must be considered. The committee considered social acceptance with a recognition that the security of a system and infrastructure are additional important factors.

In terms of infrastructure, the committee appreciated the important role of government-provided infrastructure, including regulations. "I think this recognition is counter to the common belief today that regulation is always bad," Lappos said, adding that a venture capitalist participating on the committee noted that a regulatory framework could increase potential investors' confidence that a path toward a technology's approval exists.

The committee's vision for advanced aerial mobility is summed up in Figure 6-3. A "purpose-built" air traffic system, largely akin to the existing FAA system, could track the network of small and large aircraft alike with information so each vehicle is visible to all in the area, without

LOCKHEED MARTIN

[5] National Academies of Sciences, Engineering, and Medicine, NASEM). 2020. Advancing Aerial Mobility: A National Blueprint. Washington, DC: The National Academies Press

the need to build systems into each vehicle. “It’s entirely possible, with the power of network technology, to solve these [air traffic challenges] easily,” the presenter stated. “We thought we should build a system graceful enough for passengers and cargo, and which includes today’s air traffic systems for helicopters and airplanes as part of the total system.”

Environmental responsibility is central to the vision for advanced air mobility, Lappos pointed out, with noise as a particularly important consideration in this realm. The economics of new electric- and battery-powered vehicles support an environmentally friendly airspace, given that these vehicles are “likely to be extremely inexpensive,” according to Lappos. With electric motors and batteries replacing the expensive systems in traditional helicopters, for example, “the simplification is amazing” and can result in much lower costs for purchase and operation.

There are gaps that must be addressed in system characteristics in the aerial mobility context. Safety issues, including air traffic management, are number one, Lappos stressed, and safety systems must be developed to allow vehicles to operate without endangering the public. The vertical-lift characteristic represents an advantage because, with careful consideration to needed safety considerations, the vehicles will be able to “pull over” to the side like cars pull off the road.

Lappos also mentioned gaps related to the air vehicles themselves, predicting that perhaps only 20 or 50 or so of the 205 different air vehicles that were in development in early 2020 would actually enter the marketplace.

In terms of barriers to the ambitious vision for advanced aerial mobility, Lappos stressed the importance of collaboration, including public-private partnerships. Representatives from different sectors must meet and commit to particular tasks, while recognizing the FAA’s critical regulatory role in areas such as public protection; NASA’s capabilities as a leader in the technology arena; and the regulatory role of government in providing leadership on additional issues, including noise.

Seeing the report’s vision through could take 15 years, as an urban environment is built to safely and efficiently accommodate a multitude of air vehicles. “But we have to start somewhere,” he encouraged, referencing a two-year goal for developing a plan following up on the report. Some sectors are already taking advantage of aerial mobility’s promise with package delivery vans being designed for these modern vehicles to sit atop their roofs to cost-efficiently carry packages their last mile or two.

Figure 6-4 highlights formal recommendations by the NASEM committee. Lappos emphasized the need for a national plan, established through a public-private partnership and with assigned goals and milestones. The National Academies “is one of the great places to focus on this,” he said, adding that Congress should be involved to ensure an understanding of society’s will and commitment to pursuing this type of sophisticated aerial mobility system.

Lappos reiterated the significant benefit of a network allowing vehicles to communicate with each other automatically. Developing this system would naturally take time with the NASA Grand Challenge as a terrific tool for formalizing best practices. His committee discussed the usefulness of NASA and the FAA working together on an air traffic management network with similarities to the Automatic Dependent Surveillance-Broadcast (ADS-B) air traffic control system.

Of the recommendation to research the envisioned aerial mobility system’s societal impact, Lappos spotlighted the importance of appropriate noise and safety regulations and certification rules. The committee raised the prospect of standardized advanced aerial mobility test facilities. These would allow researchers and applicants to conduct flights and make measurements under identical circumstances, toward better understanding the vehicle impacts and helping to ensure certification preparedness.

Note-The National Academies report recommended:
"Research should be performed to quantify and mitigate public annoyance due to noise, including psychoacoustic and health aspects, from different types of advanced aerial mobility operations. NASA should facilitate a collaboration between relevant government agencies—including FAA, Department of Defense, National Institutes of Health, academia, state and local governments, industry, original equipment manufacturers, operators, and nonprofit organizations—to prioritize and conduct the research, with responsibility allocated per a coordinated plan and accountability for delivery incorporated. The research should be completed in 2 years."—Ed.

Figure 6-1 *NASEM committee statement of tasks*

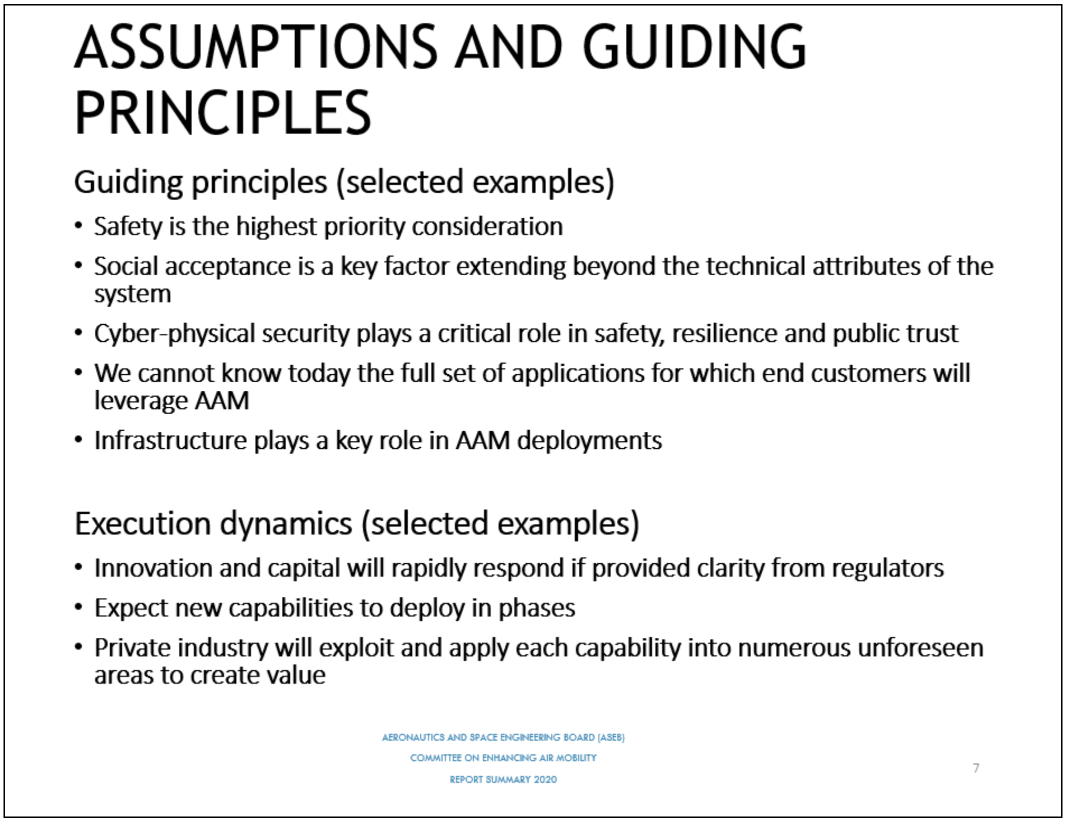


Figure 6-2 *NASEM committee assumptions and guiding principles*

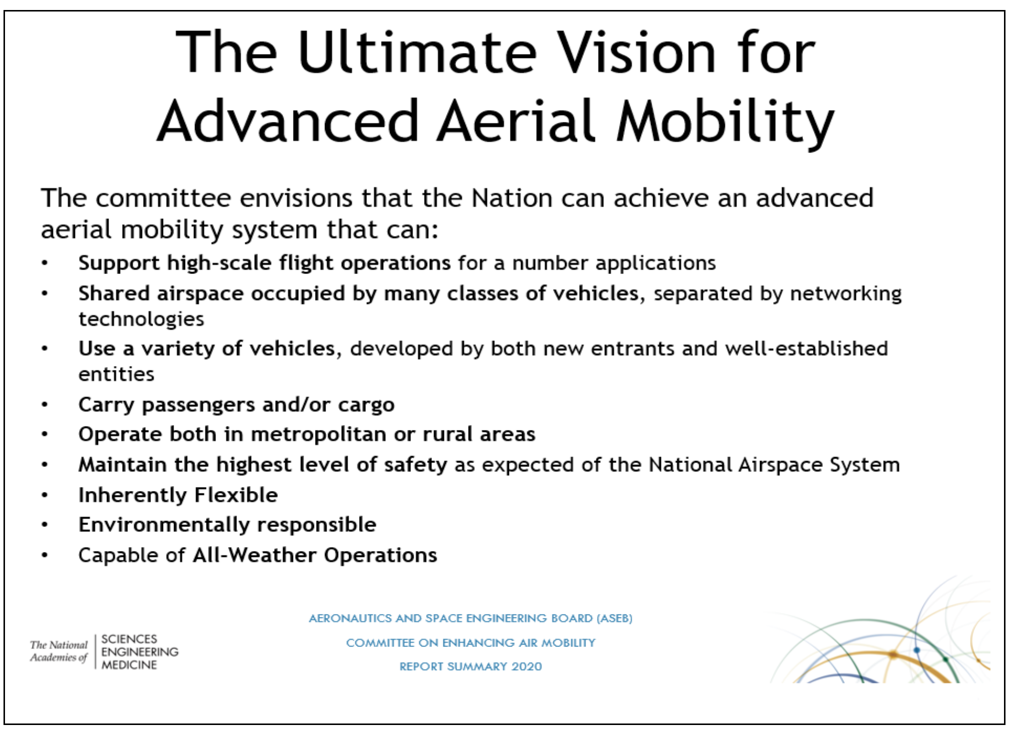


Figure 6-3 *The ultimate vision for advance aerial mobility*

COMMITTEE RECOMMENDATIONS

Process to facilitate progress and collaboration

Form a Coordinated, Joint National AAM Plan
Prepare the National Airspace System to Integrate AAM
Use the NASA Grand Challenge to Formalize Best Practices
Establish Public-Private Partnerships

Forward-looking applied research

Research to Address Societal Impact
Address Safety in Software Intensive Systems
Develop Cybersecurity Applied to AAM
Develop Certification Techniques for AAM
Research and Develop Contingency Management
Establish Data Protocol Standards

Facilitating near-term execution and U.S. competitive advantage

Develop the Marketplace for First Adopters
Create AAM Test Facilities

AERONAUTICS AND SPACE ENGINEERING BOARD (ASEB)
COMMITTEE ON ENHANCING AIR MOBILITY
REPORT SUMMARY 2020

Figure 6-4 *NASEM committee recommendations*

7. Keynote Address: A Brief Summary of the Quiet Drones 2020 e-Symposium

Jean Tourret—INCE/Europe

Regulatory authorities and companies in Europe and across the world are making important strides in the integration of unmanned aircraft into the airspace, yet formidable challenges remain, including a dearth of evidence on health effects and a lack of useful metrics to develop standards and regulations. INCE/Europe's Quiet Drones 2020 e-symposium addressed noise-associated progress and hurdles alike, in the context of the immature and fast-evolving aerial mobility sector.

INCE/Europe president Jean Tourret spoke about his group's Quiet Drones 2020 e-Symposium, which was held virtually in October 2020 and which Tourret co-chaired with INCE/Europe director Dick Bowdler. In this keynote presentation for the aerial mobility workshop, Tourret represented his and Bowdler's perspectives, as well as those of Philippe Strauss with CidB, which partnered with INCE/Europe in organizing the symposium. CidB is Le Centre d'information et de documentation sur le bruit. It is a place of resources and dissemination of information dedicated to promoting the quality of our sound environment.

Quiet Drones 2020 was initially planned for May as a physical symposium in Paris, but was ultimately held as a virtual meeting because of COVID-19. The workshop attracted 80 abstracts and included 55 prerecorded presentations within 10 sessions. Registrants included 170 delegates from 22 countries—30 from the Americas, including 24 from the United States; 25 from the Asia-Pacific region; and more than 100 from Europe. Forty-six papers were published in the more than 500-page proceedings. Two-hour technical sessions covered a wide variety of topics, with informal "conversation sessions" addressing additional subjects.

In the first introductory lecture, Robert Hellweg summarized the 2018 *Technology for a Quieter America* workshop, hosted by the National Academy of Engineering, focusing on UAS and UAV noise and associated noise control technologies.

The second introductory lecture, about noise as a possible hurdle to progress on drones, was given in two parts by Carine Donzel, secretary general of the Civil Drone Council of the French Civil Aviation Authority known by the acronym DGAC; and Henry de Plinval, director of the drone program of the French aerospace lab ONERA. Donzel summed up the Civil Drone Council's activities and associated research funding from the DGAC, as presented in Figure 7-1. De Plinval then provided a brief overview of ANIMA, a large, ongoing European project led by ONERA, and the findings most likely to be potentially applicable to drones are shown in Figure 7-2 - including the need for empowerment of the conclusions reached by all participating stakeholders, and the promise of enhanced communication with affected communities for mitigating the adverse impacts of noise.

"Drone Noise, a New Public Health Challenge" was the title of the third introductory lecture, by Antonio Torija Martinez of the University of Salford in Great Britain. He addressed five general categories of challenges and research gaps related to drone noise, which are listed in Figure 7-3 and include the inapplicability to drones of current evidence about the health effects of aircraft noise, and the lack of useful metrics.

Nine technical sessions followed the introductory session. Topics are listed in Figure 7-4, with the number of presentations on each subject matter included parenthetically.

INCEEUROPE

Tourret highlighted the symposium's Session 3, about specific noise concerns with packages and deliveries. Four papers were presented to the 60 attending delegates. Marion Burgess with the University of New South Wales (UNSW) Canberra discussed the trial of direct-to-household drone delivery by Wing company drones in the Canberra region of Australia. The experiment presented an opportunity for the Australian government to assess operations and seek community response for consideration within a regulatory framework. Also, it was a chance for operations to be reviewed by Wing, which took steps toward reducing community annoyance by switching to a delivery drone with a 7 dB lower noise level and also giving additional attention to flight paths. Following the successful trial and actions to reduce noise impact, the company won approval to operate in two additional jurisdictions. "The new operation has been successful, with very few complaints," Tourret said.

A symposium presenter listed in Figure 7-5 was Phillipe Cassan of DPD group / La Poste FRANCE. The service operated two drone delivery lines in rural areas of France—one in the southeast, to an isolated small- and medium-sized enterprise incubator, and the other to a remote village in the Alps—with no complaints received about noise.

Eddie Duncan with Resource Systems Group Inc. (RSG) discussed commercial delivery drone routing and noise impacts, presenting a case study of the use of community noise mapping as a tool to reduce noise impacts. Approaches for reducing noise focused on optimizing flight routes to reduce population noise exposure, and also on increasing sound masking. The methodology relied on sound propagation models of drones, coupled with existing noise maps and background sound level data. Analysis of four routing scenarios revealed that options over undeveloped lands and waterways resulted in the lowest overall exposure to drone noise, while routes over more populated areas could result in lessened noise impact by following roadways to take advantage of the masking effect of traffic noise.

A question and discussion period followed these Session 3 presentations. Issues discussed included the need to: share data on noise emissions; apply different levels of certification for urban, rural, and mixed applications; and develop specific traffic management regulations to support sharing of airspace among drone operators as well as air taxis.

The symposium's Session 4, which focused on standardization and regulations, was attended by more than 100 delegates. David Read and Christopher Roof, with the U.S. Department of Transportation's Volpe Center, discussed research to support new aerial mobility entrants into the public airspace and aircraft noise certification. Figure 7-6 presents major considerations, including that noise from these new aircraft may be substantially different from what the public has previously experienced, and that existing aircraft noise certification methods may not fully address needs as these new vehicles enter the airspace. With likeminded partners, Volpe is conducting ongoing research measurement programs to obtain data that can inform policy.

Continuing on the theme of standardization and regulations, Nicolas Eertmans from the European Commission's Directorate-General for Mobility and Transport, DG MOVE, discussed the EU's regulatory framework for unmanned aircraft. DG MOVE has introduced three categories of operations: "open," for low-risk operations, which are not conditional on prior operational approval; "specific," for medium-risk operations, which require the authorities' approval of a risk assessment; and "certified," for the highest-risk operations, to which the traditional aviation regulatory framework is applied.

To adequately protect citizens, noise emissions must be limited, especially from "open"-category commercial operations occurring near people. So far, however, with limited drone operations has come limited assessment of how drone noise may affect people and little objective data to define a maximum allowable contribution from drones to environmental noise. Tourret briefly discussed highlights of DG MOVE's regulatory approach, as presented in Figure 7-7, while emphasizing the difficulty of being forward-looking given the infancy of the unmanned aircraft sector. Figures 7-8 and 7-9 present characteristics of each class of unmanned aircraft in the open category and corresponding EC maximum sound power levels, respectively.

Two more presentations rounded out the discussion of standardization and regulation: Robert Hellweg discussed ANSI/ASA standards related to UAS noise measurement. Michael Wieland, with the UAV DACH Unmanned Aviation Association, covered unmanned aircraft noise requirements under European Regulation 2019/945. A question and discussion period following presentations on standardization and regulation raised several main issues for consideration, including those set forth in Figures 7-10 focusing on standards and 7-11 focusing on regulations. For one example, it was noted that an increase in communication among manufacturers and other interested parties internationally could prove important in addressing the scarcity of informative data to support a regulatory framework. Also, as highlighted in Figure 7-11, urban air mobility vertiports are an important issue requiring noise regulation, and sound insulation for tall buildings should be adapted for new constraints associated with flyover drones.

In concluding his presentation, Tourret spotlighted these main points: The symposium confirmed that noise from drones is a broad, "hot and fast-developing" topic; the symposium was designed to cover a wide range of relevant topics, linking related information and disseminating information among interested parties; increases in research and communication are necessary for a comprehensive understanding of the issues associated with drone noise; and many challenges remain for the integration of unmanned aircraft into the airspace. During a discussion period, Tourret also commented on the historically slow pace of noise-related regulation, highlighting the example of wind turbine noise regulation that has been discussed for some two decades but has not been finalized in Europe or internationally. It took nearly 10 years to even realize that the problem of wind turbine noise is generally attributable to modulation of noise rather than infrasound frequency.

You can find more information about the 2020 Quiet Drones e-Symposium by visiting https://www.quietdrones.org/. There, you can access a free program book with abstracts from the 2020 presentations, purchase a copy of the full proceedings, and find information as it becomes available about the planned 2022 Quiet Drones conference.

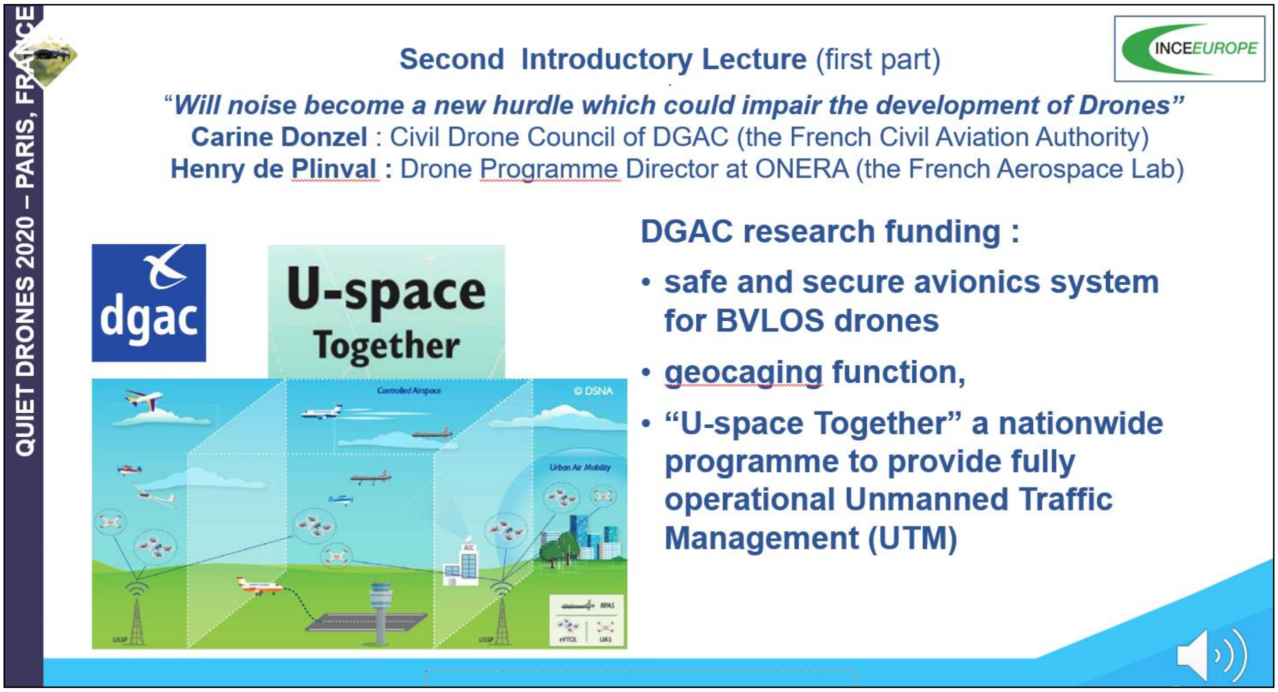


Figure 7-1 DGAC-funded research activities

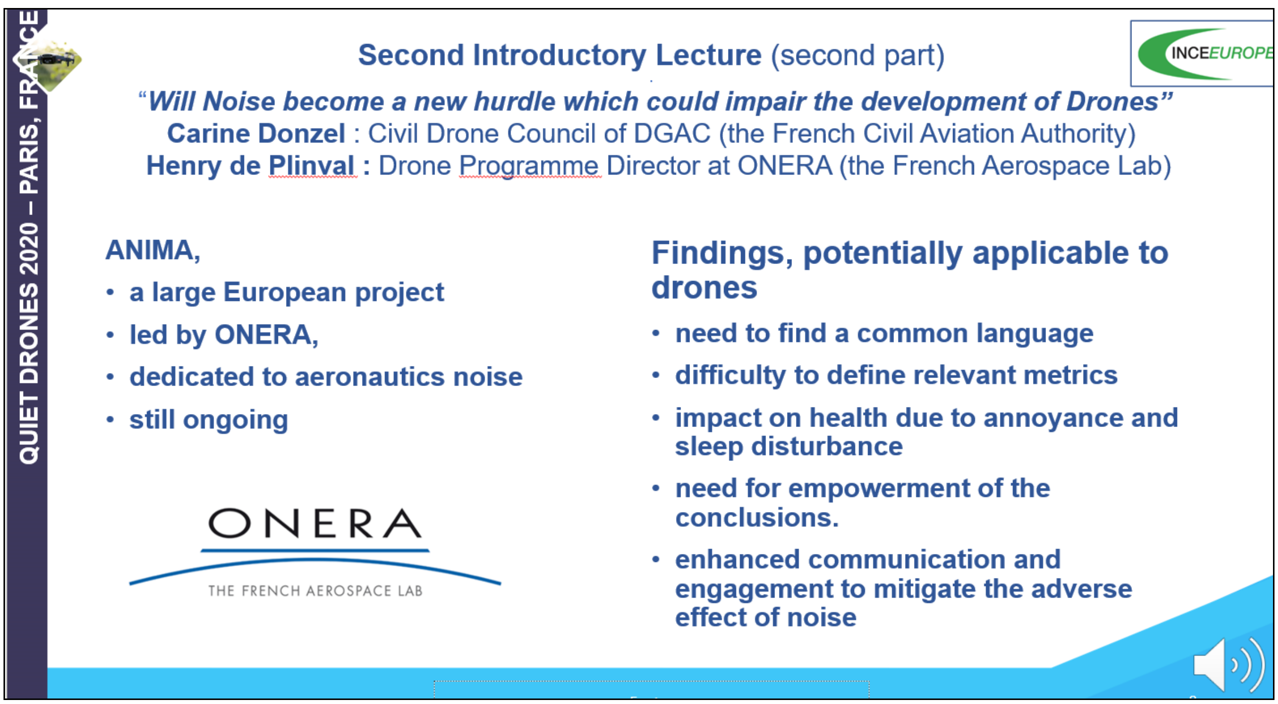


Figure 7-2 ANIMA findings potentially relevant to drones

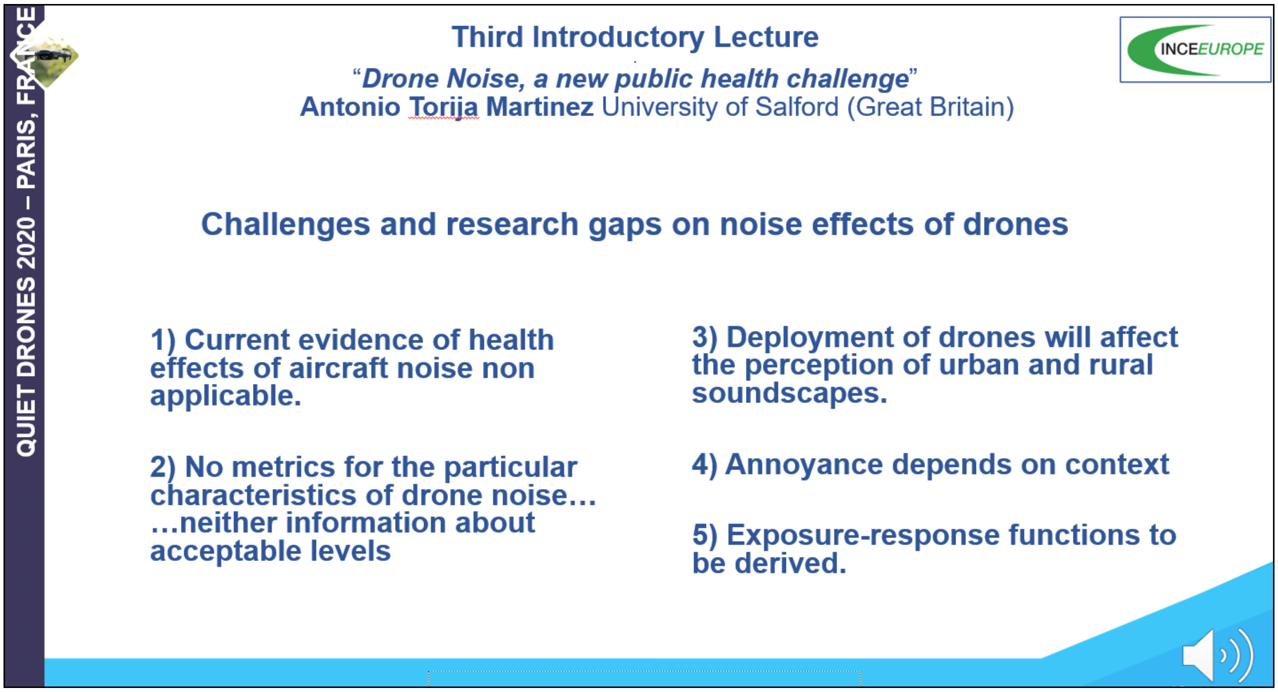


Figure 7-3 *Challenges and research gaps on noise effects of drones*

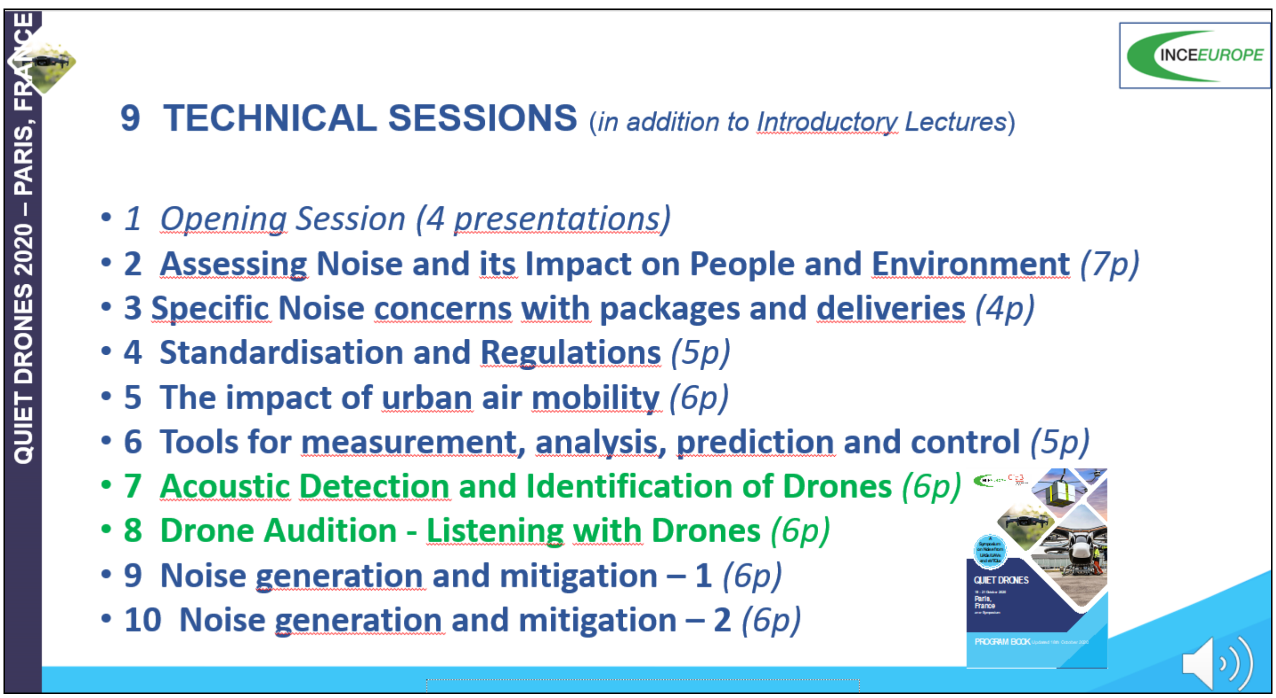


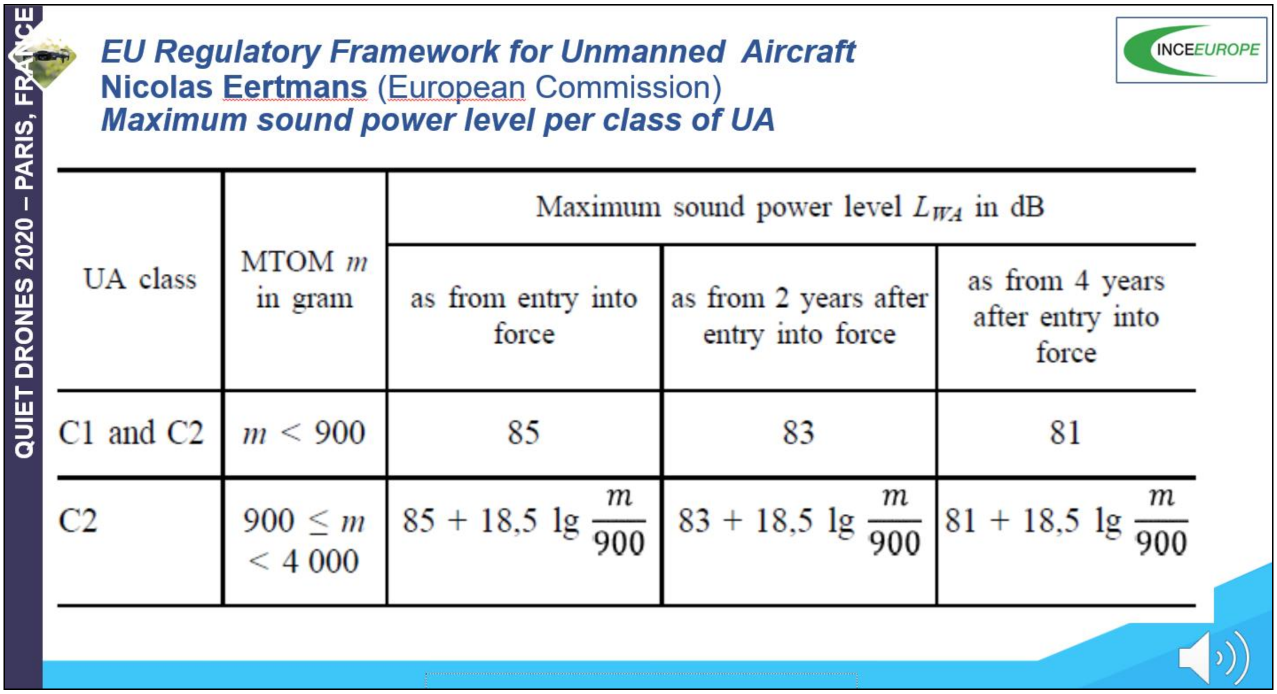
Figure 7-4 *Quiet Noise e-symposium's technical sessions*

Figure 7-5 *Rural drone delivery service led to no noise complaints*

Figure 7-6 *Integrating new vehicles into the airspace raises distinct considerations*

Figure 7-7 *EU's unmanned operations categories and regulatory concepts*

Figure 7-8 *Characteristics of EU regulation - "open"-category unmanned aircraft*



UA class	MTOM m in gram	Maximum sound power level L_{WA} in dB		
		as from entry into force	as from 2 years after entry into force	as from 4 years after entry into force
C1 and C2	$m < 900$	85	83	81
C2	$900 \leq m < 4\,000$	$85 + 18{,}5 \lg \frac{m}{900}$	$83 + 18{,}5 \lg \frac{m}{900}$	$81 + 18{,}5 \lg \frac{m}{900}$

Figure 7-9 *Maximum EU sound power levels per class of UA*

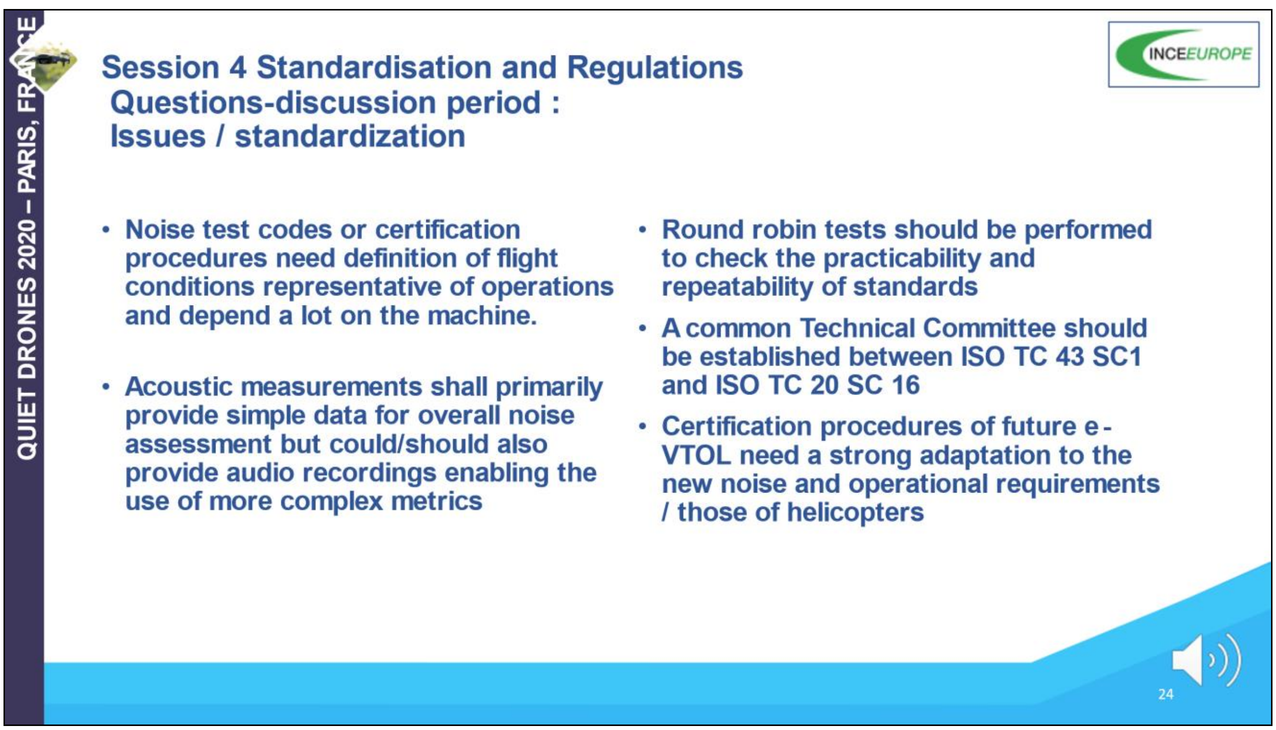


Figure 7-10 *Standardization-related issues*

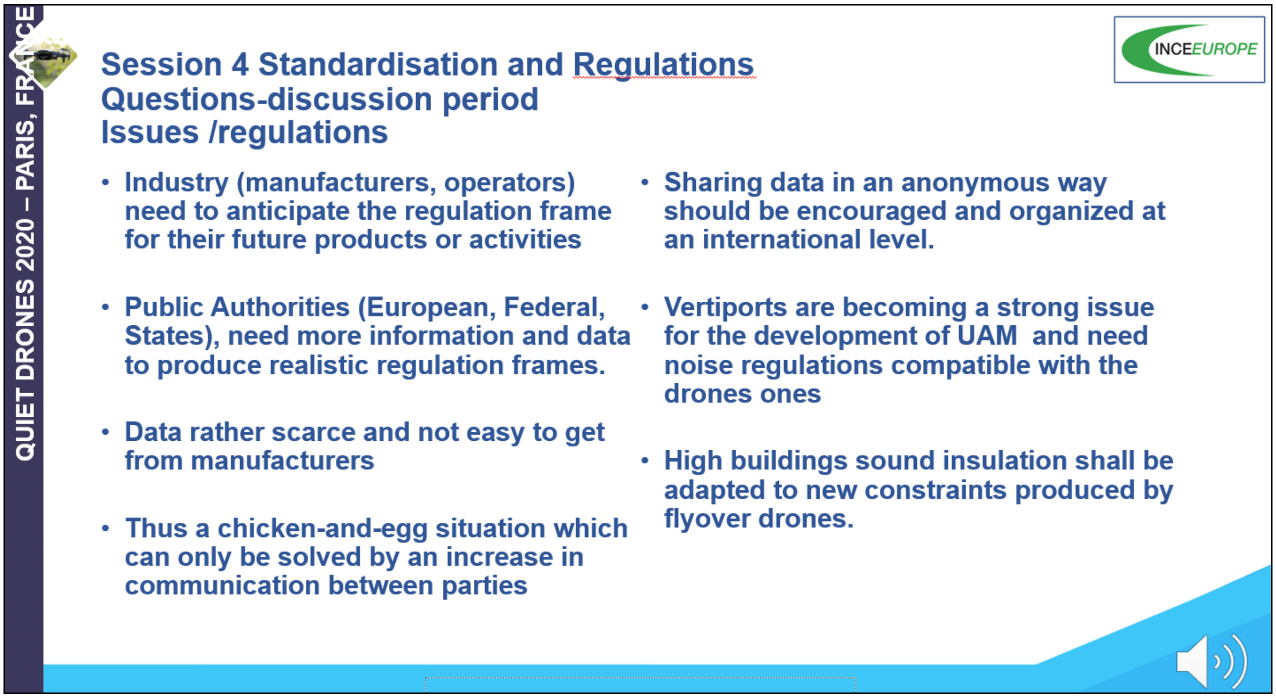


Figure 7-11 *Regulation-related issues*

8. Summary of the UAM Noise Working Group White Paper

Stephen Rizzi—NASA

NASA has formed a working group to define and address UAM-related noise issues. Made up of a broad range of stakeholders, the Urban Air Mobility Noise Working Group addresses UAM issues in four high-level areas: tools and technologies, ground and flight testing, human response and metrics, and regulation and policy. The group published a white paper in October 2020 covering current practice and related gaps, and providing recommendations, in support of progress in the four areas.

Stephen Rizzi, Senior Researcher for Aeroacoustics at the NASA Langley Research Center, spoke in this first of his two workshop presentations about the Urban Air Mobility Noise Working Group (UNWG) and its recent white paper, titled *Urban Air Mobility Noise: Current Practice, Gaps, and Recommendations*.

As background, Rizzi led up to his main focus of the white paper with a brief discussion of the related recommendation on noise in the National Academies report *Advancing Aerial Mobility: A National Blueprint* published in 2020[6] . The report stated that "public acceptance of advanced aerial mobility, particularly noise aspects and its psychological factors, is perhaps one of the biggest challenges along with safety." And the report recommended that:

> Research should be performed to quantify and mitigate public annoyance due to noise, including psychoacoustic and health aspects, from different types of advanced aerial mobility operations. NASA should facilitate a collaboration between relevant government agencies—including FAA, Department of Defense, National Institutes of Health, academia, state and local governments, industry, original equipment manufacturers, operators, and nonprofit organizations—to prioritize and conduct the research, with responsibility allocated per a coordinated plan and accountability for delivery incorporated. The research should be completed in 2 years.

In a separate undertaking with a closely related focus, a NASA-organized exploratory meeting in April 2018 focused on UAM noise. Participants supported the formation of a focused working group—with a broad representation of stakeholders from industry, government, academia, and community groups—to define and address noise issues associated with UAM vehicles. Key topics of interest for this group, which was organized under the name "Urban Air Mobility Noise Working Group," include: Tools and Technologies (Subgroup 1, led by NASA), Ground and Flight Testing (Subgroup 2, led by NASA), Human Response and Metrics (Subgroup 3, led by NASA), and Regulation and Policy (Subgroup 4, led by the FAA).

The working group focuses on UAM vehicles and operations with attributes including: six or fewer passengers (or equivalent cargo), a single pilot or autonomous control, approximately 100 nautical-mile missions flown under 3,000 feet above ground level, flight speeds of 200 knots or less, payloads in the range of 800 to 8,000 pounds, and electrical vertical takeoff and landing (eVTOL) with either all-battery power or hybrid-electric propulsion.

[6] (National Academies of Sciences, Engineering, and Medicine 2020. *Advancing Aerial Mobility: A National Blueprint*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25646).

One of the working group's high-level goals is also the focus of its recent white paper: Document noise reduction technologies available for UAM and identify knowledge gaps for each of the four areas of interest. The group's additional goals are summarized in Figure 8-1.

Moving next to the white paper itself, published in October 2020, Rizzi specified that the paper was published as NASA/TP-2020-5007433 [7]. The speaker highlighted some of the recommendations from the white paper by key topic:

Tools and Technologies

"It is recommended that:

• System noise prediction tools be further developed for application to UAM vehicles and made available to the research and industrial communities.
• Research be performed to develop conventions on how to handle control redundancies to obtain preferred low-noise trim conditions and to further develop the acoustic tools to handle aperiodic sources.
• Prediction models for the highest amplitude noise sources be validated with experimental data for isolated and installed configurations, and that flight test data be acquired to better understand variations under realistic operating conditions, particularly unsteady conditions (e.g., maneuvers and transition).
• Continued development of auralization tools be performed to allow realization of flight operations (including takeoff, forward flight, landing, and transition) for a representative range of vehicle configurations."

Rizzi explained that auralization is the process by which these predictions are turned into audible sounds that can be used for purposes such as psychoacoustic studies, noting too that the next release of the NASA Auralization Framework software, with new capabilities for UAM noise, is expected in spring 2021.

"• A dedicated technology maturation effort be performed on the most promising noise mitigation technologies and that opportunities be sought to evaluate their efficacy in flight.
• Surrogate or other reduced order model methods be developed so that designers can quickly determine the effects of design changes on noise early in the design process, and that sensitivities be fully implemented to enable optimization of low-noise vehicle designs and operations."
The speaker stated that NASA Langley is working on developing surrogate models using machine learning.
"• Research be conducted to more fully explore limitations in methods for assessing community noise impact of UAM vehicles in their operational environments, and to generate a software development plan that addresses the limitations of current models over time."

Ground and Flight Testing

"It is recommended that:

[7] https://ntrs.nasa.gov/search?q=20205007433

• Test environment constraints (e.g., ambient levels, benign meteorological conditions), similar to those in ICAO Annex 16 Vol. I and 14 CFR Part 36, be used for all tests conducted to measure UAM vehicle noise.
• Significant on-aircraft instrumentation and monitoring of the vehicle state be required due to varying levels of autonomy and potential increase in degrees-of-freedom of the flight envelope.
• Stakeholders (including manufacturers, researchers, and certification authorities) closely collaborate in the development of new measurement approaches."
Regarding this recommendation, Rizzi mentioned the NASA National Campaign, a series of flight demonstrations over the next several years, will collect acoustic measurements.
"• Use of flush mounted or inverted microphones over a rigid ground plane be specified as part of any future noise certification procedures."

Human Response and Metrics

"It is recommended that:

• Efforts be made to acquire/generate measured and simulated vehicle acoustic data, and to make those data available to support subjective response studies for metric and predictive model development.
• Standardized processes for measuring and cataloging ambient noise be developed, and those data be made available to support subjective response studies for metric and predictive model development.
• Until early entrants are fielded, and community noise studies can be performed, laboratory studies be performed to help inform how different the annoyance to short-term exposure of UAM vehicle noise is from that of existing aircraft noise sources. Assessments can then be made to determine the sensitivity of noise exposure estimates to changes in the metric or to its level.
• Validated models for audibility, noticeability, and annoyance to UAM aircraft noise be developed to assess their utility for assessing community noise impact."
The speaker clarified that a different measure of human response such as annoyance could be incorporated as a design constraint beyond those metrics for certification, e.g., beyond sound exposure level, but in a similar way one would design a vehicle to meet certification requirements.
"• A laboratory test campaign be used to explore differences in perception of UAM vehicle noise between communities, so that future policy decisions are based on data representing a wide range of environments."

Regulation and Policy

"It is recommended that:

• At the national level, the FAA, in collaboration with other agencies and the industry, address certification, standards, and environmental reporting for UAM noise before these vehicles enter service. This is occurring with NASA as well as with industry, Rizzi pointed out.
• More data be collected in the field through R&D programs and data from manufacturers be leveraged."

After the presentation, Gregg Fleming posed a question to the speaker about whether ANOPP2 (NASA's second generation Aircraft NOise Prediction Program) offers sufficient flexibility to allow for different levels of fidelity in characterizing a source. Is ANOPP2 flexible enough to allow for source noise characterization with very basic certification measurements such as only three microphones, for example? "Certainly," Rizzi responded, stating that his second presentation, about the FAA AEDT (Aviation Environmental Design Tool) for UAM noise assessment, will show how NASA is using ANOPP2 and an ANOPP2 tool called AARON (ANOPP2 Aeroacoustic ROtor Noise) to generate source noise hemispheres for subsequent propagation through ANOPP2 to receivers on the ground—for pre-certification prediction and to generate Noise Power Distance Data, or NPDs.

UNWG High Level Goals

- **Document noise reduction technologies available for UAM and identify knowledge gaps for each of the four areas of interest (UNWG subgroups).**
- Assess prediction capabilities for benchmark problems based on an open set of reference vehicle designs using available data.
- Define measurement methods/procedures to support noise regulations and assessment of community noise impact, and coordinate with UAM vehicle manufacturers on development of low noise approach and takeoff procedures for piloted and automated operations.
- Assess metrics for audibility and annoyance of single-event vehicle operations using available predicted and measured data.
- Examine fleet noise impacts through prediction and measurement, and characterize effectiveness of supplemental metrics for audibility and annoyance.
- Promote UAM integration into communities through mitigation of fleet noise impacts, and engagement with the public.

Figure 8-1 *Goals of the UAM Noise Working Group*

9. FAA Perspective on Aerial Mobility

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James Hileman—FAA

The FAA's responsibilities include regulating noise from smaller aircraft such as aerial mobility vehicles. The agency is applying lessons learned through research on subsonic aircraft—and on helicopters, with their distinct noise characteristics—to guide its air mobility research. Meanwhile, the FAA is also establishing suitable certification approaches for air mobility vehicles.

James Hileman, the Federal Aviation Administration's chief scientific and technical advisor for environment and energy, spoke about aerial mobility noise issues, noting up-front that many of his points are likewise relevant to other modes of air transport. The FAA is charged with protecting the public health and welfare from aircraft noise, a role included in the Code of Federal Regulations and also in airworthiness standards for certification of air vehicles.

The FAA is responsible for noise from smaller aircraft such as aerial mobility vehicles (as well as from commercial space launches) under the National Environmental Policy Act (NEPA). Under NEPA, and in recognition that community exposure to aircraft noise can vary greatly based on factors such as people's locations relative to the aircraft and operational circumstances, the act relies on a cumulative noise exposure metric known as the day-night average sound level, or DNL.

Hileman focused early in his presentation on subsonic aircraft noise, presenting Figure 9-1 highlighting some important facts. Aircraft noise has been significantly reduced since the advent of jet aircraft in the 1960s and their early widespread use in the '70s, the presenter said. In fact, 10 to 30 of today's aircraft operations produce the same amount of noise as a single operation in the 1970s; and about 7 million people were exposed in the 1970s to a DNL of at least 65 dB, compared to approximately 400,000 people today.

But today's cumulative effects of noise experienced many times daily is potentially more annoying than the experience of past eras, with less frequent, but louder aircraft. Precision navigation, a technology implemented recently to increase the safety and efficiency of the national airspace, resulted in negative consequences for noise. With flight routes concentrated into narrow corridors, fewer people are impacted by aircraft noise, but for those directly beneath these corridors they've seen an increased exposure to aircraft noise. These people are frustrated, the presenter said—and vocal about it.

Noting the impact of coronavirus, Hileman said that the pandemic halted much of the usual air traffic for a time. Post-pandemic, people may regard returning traffic as creating "new" noise, and advanced air mobility vehicles may contribute to this experience of noise by the public.

People in various parts of the country have raised concerns about helicopter noise. Particular issues associated with helicopter noise are listed in Figure 9-2. Anecdotal evidence suggests that people are troubled by helicopter noise at levels "far below" the levels of fixed-wing aircraft that similarly concerns them. Rotary aircraft present a very different noise experience than fixed-wing aircraft. The fundamental frequency of the blade passage is the familiar low "whop-whop-whop," with periodic and impulsive attributes. The low-frequency noise also travels farther and lasts longer, and the complex aerodynamics of helicopters create a multitude of complex sound sources.

The FAA is leveraging extensive subsonic aircraft and helicopter research, conducted largely by the Volpe Center and its ASCENT Center of Excellence, to shed light on unmanned aircraft systems and advanced air mobility. Hileman briefly discussed some examples of ASCENT research projects. In one such project, Georgia Tech is developing metrics for quantifying community noise from UAS/AAM, which will complement the FAA's Aviation Environmental Design Tool (AEDT). In another example, a Penn State University helicopter noise prediction model has shown "very good success" when compared with Volpe and NASA measurements. These and three additional research studies are summarized in Figure 9-3.

In winding down his presentation, Hileman emphasized that the FAA is conducting research to support appropriate certification procedures for advanced air mobility vehicles. Ongoing research is needed for a fuller understanding of differences in physical configuration and propulsion systems, operational characteristics, noise mitigation methods, and ways to optimize communication. The FAA works very closely with NASA and the Volpe Center and welcomes opportunities to collaborate with others in government, industry, and academia.

Asked by an attendee how the FAA works with counterpart organizations in other countries, Hileman responded that the agency has regular bilateral discussions with certification authorities in various countries, and works with certification authorities worldwide through the Committee on Aviation Environmental Protection (CAEP), a technical committee of the International Civil Aviation Organization. Hileman noted that a CAEP technical working group on noise is co-chaired by another workshop speaker, the FAA's Donald Scata.

Another attendee asked whether the FAA is studying the impacts of small delivery drones including the overall impact of noise. Hileman responded that a substantial FAA research program studies sleep-related and other health effects of fixed-wing aircraft, and to a limited extent helicopters, but that the agency is not at the point yet of considering these types of effects from UAS.

In response to another attendee's question, Hileman clarified that the findings on community response to helicopter versus fixed-wing aircraft noise are based on people's responses to questions about their annoyance from operations over a one-year period in which they are asked how much does noise from source X bother you over the last 12 months. This type of question aligns with recommendations from the International Commission on Biological Effects of Noise (ICBEN), the presenter said.

Responding to another attendee's question, Hileman explained that all air vehicles are currently considered similarly by the FAA with respect to noise regulation, but he stressed that the FAA's approaches may change. Hileman added that the FAA is grappling with complex issues associated with preeminence of federal aviation regulations over state and local ones.

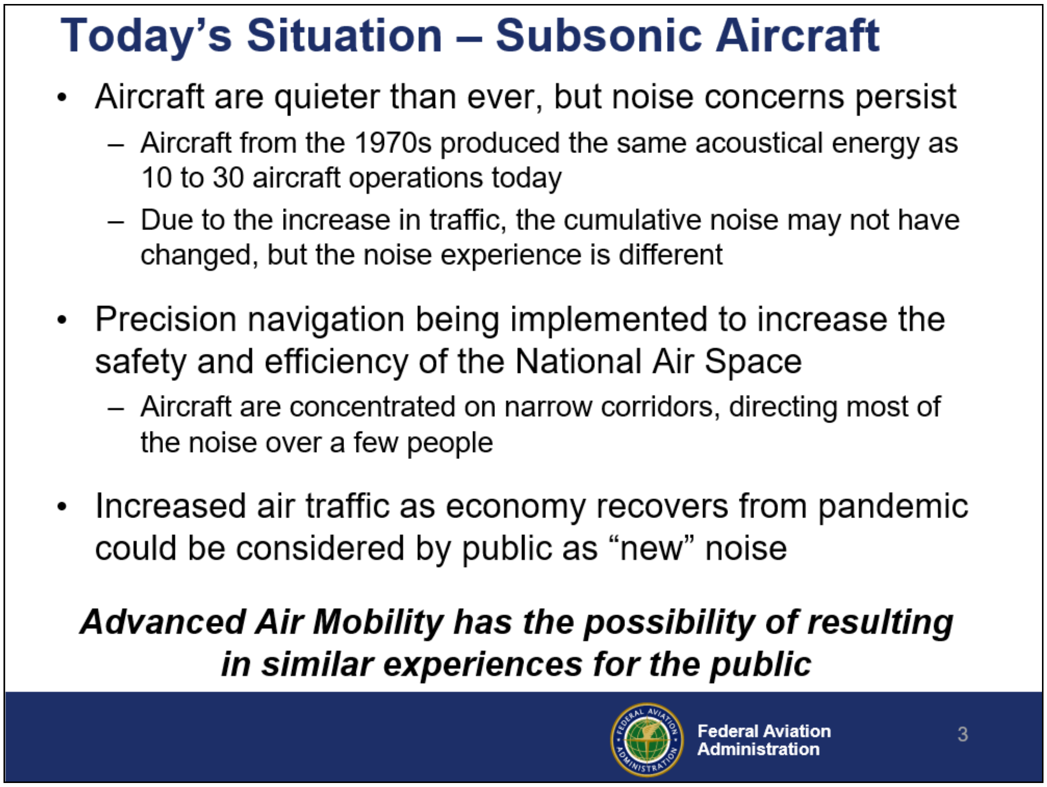

Figure 9-1 *Today's situation - subsonic aircraft*

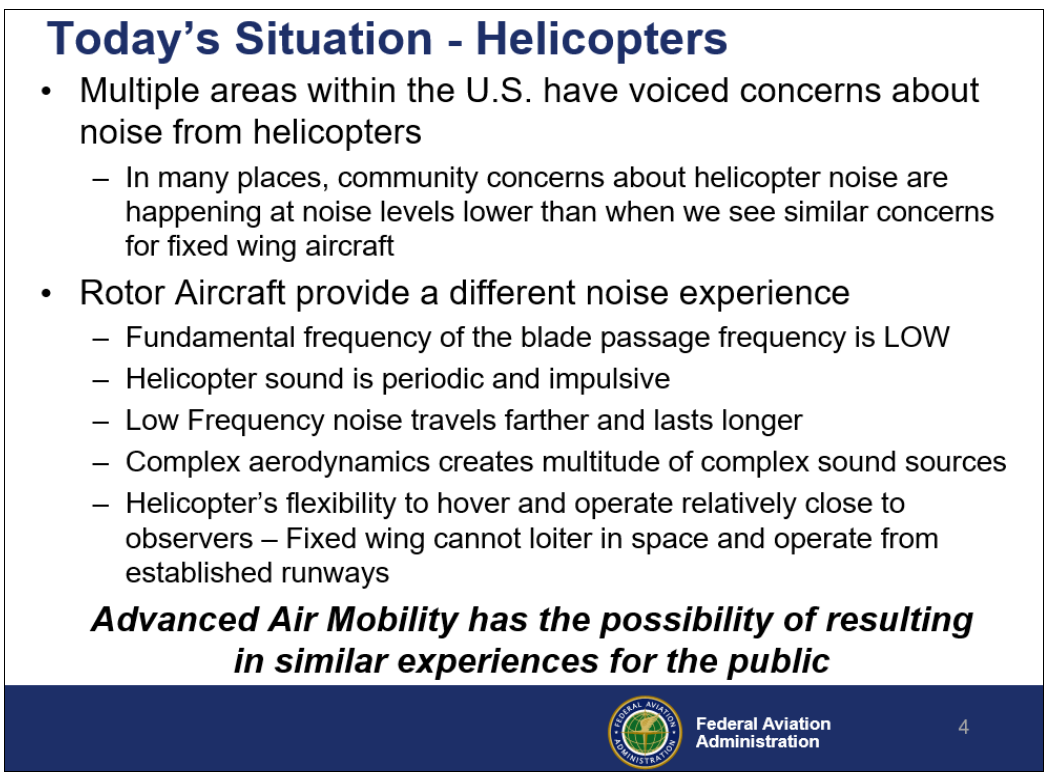

Figure 9-2 *Today-s situation - helicopters*

Research Direction

- Leveraging noise research on subsonic aircraft and helicopters to inform direction for Unmanned Aircraft Systems (UAS) and Advanced Air Mobility (AAM)
- Work largely being done by Volpe Center and ASCENT COE

ASCENT Projects	University	Research Direction
ASCENT P9: Geospatially Driven Noise Estimation Module	Georgia Tech	Supporting computation of noise resulting from the operation of UAS/AAM and other upcoming vehicle concepts.
ASCENT P38: Rotorcraft Noise Abatement Procedures Development	Penn State	Using a physics based model to predict noise for steady state and maneuvering rotorcraft operations in order to develop noise abatement procedures.
ASCENT P49: Modeling of Urban Air Mobility Noise to Enable Innovative Means of Noise Reduction	Penn State	Extending work of Project 38 to UAS/AAM by modeling multiple lifting rotors and propellers, both ducted and unducted, and their interaction with each other and the airframe.
ASCENT P61: Noise Certification Streamlining	Georgia Tech	Developing concepts for a streamlined and flexible approach to certify current, emerging, and future air vehicles.
ASCENT P77: Measurements to Support Noise Certification for UAS/UAM Vehicles and Identify Noise Reduction Opportunities	Penn State	Conducting laboratory and field flight measurements of vehicles of various design types and flight characteristics and to investigate factors contributing to noise levels and variation.

For more information on ASCENT research projects, please visit: https://ascent.aero/project/

Federal Aviation Administration

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Figure 9-3 UAS/UAM research direction

10. Overview of Future Noise Certification Needs for Aerial Mobility Aircraft

Donald Scata Jr.—FAA

Noise certification of aerial mobility aircraft is a critical element for the smooth assimilation of these new vehicles into the national airspace. As the certifying authority for all U.S. commercial aircraft, the FAA is addressing research and policy challenges associated with certification of these emerging types of vehicles, whose characteristics such as flight and noise profiles can diverge significantly from those of traditional aircraft.

Following up on the presentation by the FAA's James Hileman, Donald Scata, FAA Noise Division Manager with the agency's Office of Environment and Energy, shared his complementary perspective on the agency's efforts toward integrating advanced air mobility (AAM) aircraft into the U.S. airspace. Scata's presentation focused on noise certification for this emerging aircraft type. The FAA faces various questions on AAM noise, including those listed in Figure 10-1. He said: "We don't have answers to all the questions yet, but these are the things we're thinking about as we conduct research and make policy decisions."

The FAA is the certifying authority for aircraft. Its Office of Environment and Energy is responsible for noise certification regulations, while the Aircraft Certification Service within the FAA Office of Aviation Safety is responsible for implementing certification.

Scata stated that, under existing FAA regulations, the agency may require certification of all aircraft types. In its certification decisions, the FAA must consider aerial mobility aircraft's day-to-day operations, looking at elements of their operating profile such as flight altitudes and speeds, as well as noise limits and appropriate metrics and methods of noise measurement (including factors such as microphone type, orientation, and placement relative to the vehicle in flight).

Moving from this certification side to the FAA's environmental review processes under the National Environmental Policy Act (NEPA) and section 106 of the National Historic Preservation Act (NHPA), Scata pointed out that the FAA must consider noise impacts and how to integrate aerial mobility vehicles into today's regulatory approaches.

The United States participated directly in the development of International Civil Aviation Organization (ICAO) Annex 16, the worldwide noise certification standard . For domestic noise certification, the FAA uses 14 CFR Part 36, which is the U.S. equivalent of the ICAO Annex 16 and is in large part simply a promulgation domestically of the decisions made internationally.

Noise certification relies on many assumptions, and the FAA is examining whether and what revisions to these regulations may be needed when considering certification of advanced aerial mobility vehicles. As it stands, 14 CFR Part 36 includes four basic categories for aircraft certification: jet-propelled fixed-wing or large propeller-driven fixed-wing, small propeller-driven fixed-wing, helicopter, and tilt-rotor. Generally, propulsion systems have had a conventional design—mostly, internal combustion, turboprop, or turbojet for fixed-wing aircraft, and internal combustion or turbine for rotorcraft. Scata noted that the FAA has the capability to certify electric aircraft, although procedures and standards were not created with these types of vehicles in mind.

Continuing on the topic of noise certification assumptions, the presenter stated that current requirements were based by-and-large on primary flight controls, which employ movable control surfaces for fixed-wing aircraft, rotor orientation changes for rotorcraft, and a combination of these for tilt rotors. Finally, noise level on departure under current assumptions is primarily dependent on mass and power, with noise level increasing as weight and thrust increase.

While existing categories of aircraft may cover some advanced aerial mobility aircraft types, new considerations are needed for a range of AAM vehicles due to their unique noise characteristics and flight profiles. Because the FAA is still building its knowledge of AAM for certification purposes, they must consider each applicant on a case-by-case basis, using the so-called "rules of particular applicability."

The FAA works closely with the company pursuing aircraft certification on a case-by-case basis, and once both parties are comfortable with procedures, a notice in the *Federal Register* provides public notification of the FAA's intended requirements for the specific aircraft model, and the applicant is permitted to conduct testing to the published standards. In Scata's experience, first-time consideration of a particular aircraft type is the most challenging, with subsequent considerations becoming more efficient, based on observations from prior testing and the application of other lessons learned.

As FAA addresses issues associated with AAM vehicle certification, the agency benefits from valuable organizational partnerships. Figure 10-2 lists examples of important related collaborations and specific joint initiatives.

A follow-up to the FAA's Integration Pilot Program for UAS aircraft, the recently announced BEYOND program is an FAA collaboration with state, local, and tribal governments to tackle UAS-associated challenges.

In concluding his presentation, Scata emphasized the agency is interested in fostering partnerships to collect environmental information, including noise data, to improve the understanding of the acoustics of these aerial mobility aircraft and implications for their incorporation into the national airspace.

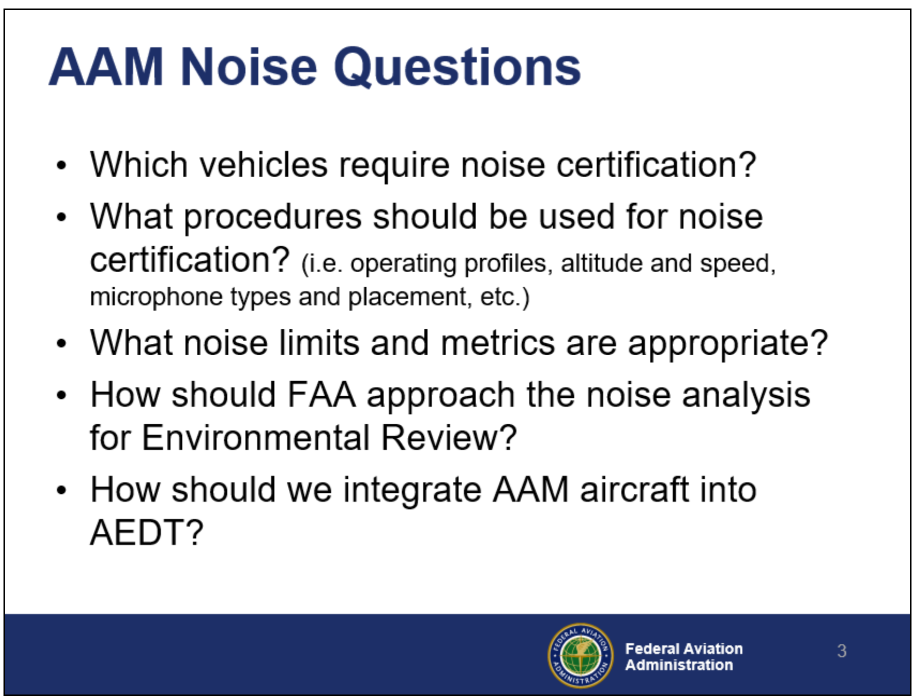


***Figure 10-1 Advanced** Aerial mobility (AAM) noise questions*

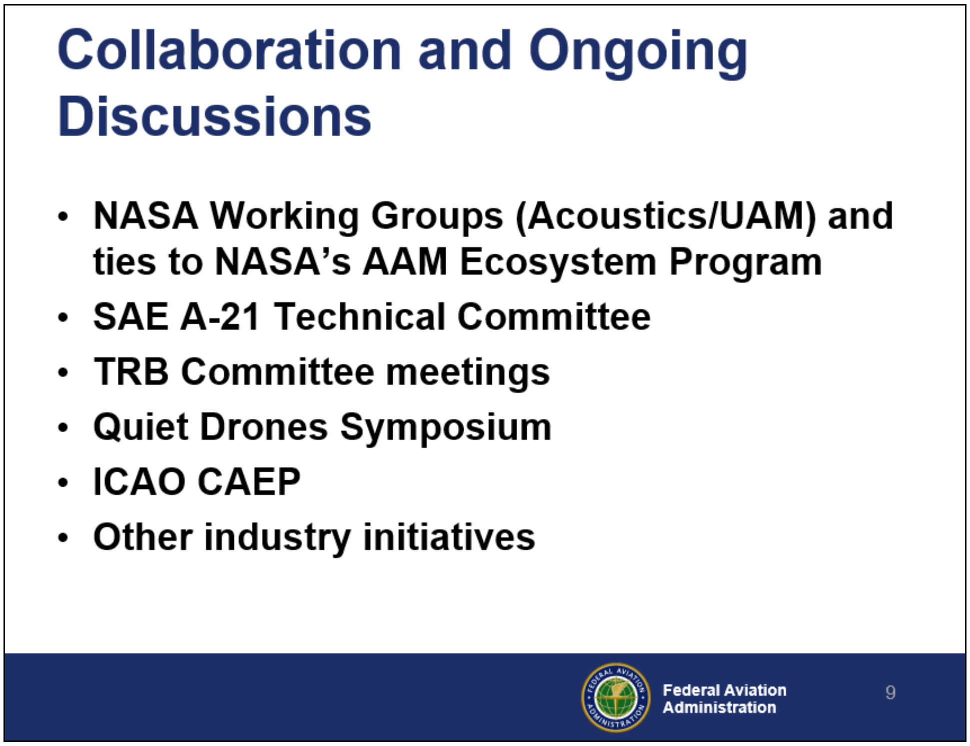


Figure 10-2 *FAA collaboration and ongoing discussions*

11. Research Considerations for Aerial Mobility and the Role of Noise Certification

David Read—U.S. DOT, Volpe National Transportation Systems Center

Public acceptance of aerial mobility aircraft will depend in large part on effective management of noise, which is heavily dependent on the instrumentation and methodology used to characterize the noise from these ultramodern vehicles. To support the FAA in the area of noise certification for unconventional aircraft, the acoustics facility within the U.S. Department of Transportation's Volpe Center shares lessons learned and makes recommendations to the FAA in this complex and evolving technical area.

David Read, an aircraft noise certification expert with the U.S. Department of Transportation Volpe Center Acoustics Facility, focused his presentation on recommendations relating to current and future research efforts for the evaluation of aerial mobility noise, as well as the Volpe perspective on instrumentation, measurement methodology, and flight procedures in the study of unconventional aircraft noise. The speaker pointed out that later in the workshop, the FAA's Don Scata would speak more specifically about policy in the context of U.S. noise regulations.

Aircraft noise certification is the method by which civil aviation authorities fulfill regulatory requirements for controlling aircraft noise. The internationally agreed-upon process for such certification is managed nationally by the FAA and internationally by the International Civil Aviation Organization. The objective of noise certification is to motivate parties to use best practices in aircraft design, and operate aircraft with preferred design elements, to meet increasingly stringent noise limits.

Figure 11-1 lays out the metrics required for noise certification by category of aircraft. Generally (see figure for additional detail):

- *For small propeller-driven, fixed-wing aircraft*: Maximum, slow time-averaged, A-weighted noise level;
- *For small helicopters*: A-weighted sound exposure level, a time-integrated metric with a reference duration of one second; and
- *For jets and large propeller-driven airplanes, large helicopters, tilt-rotor aircraft*: Effective perceived noise level (EPNL), a time-integrated metric with a 10-second reference duration.

Figure 11-2 summarizes instrumentation requirements for certification based on aircraft category. And Figure 11-3 presents the technology-enabled variety of aerial mobility vehicle designs. Read stated that the four aircraft/small UAVs shown in Figure 11-3 were tested at the Integration Pilot Program site in Oklahoma, and the two lower images were taken at the recent GoFly Fly Off competition at NASA's Moffett Field in California.

Read discussed propagation effects in aerial mobility noise, including abrupt onset and cutoff due to intermittent line-of-sight blockages. Sound reflections from nearby structures in densely populated areas may add to an unexpected variation in the "noise envelope," he explained.

In Figure 11-4, the presenter also addressed the spectral time history from a multicopter with vertical takeoff and level flight departure. The plot provides an indication of 1/3-octave-band analysis capabilities used for noise certification under Appendix A. The plot has amplitude as the vertical axis in dB SPL. The horizontal axis going downward and to the right are 1/3-octave bands for center frequencies from 20 - 20 kHz, with increasing frequency. Interestingly, even with limited frequency and time resolution, significant variation is seen in the data.

Next, the presenter referred to Andrew Christian's data in Figure 11-5, highlighting the complexity seen that is characteristic of small multicopter overflight. The spectrogram, Read clarified, was taken from a level flyover outdoors from a common DJI Phantom variant quadcopter at an average speed of about 20 feet per second (13 miles per hour) and an overhead height of about 15 feet above ground level, measured by a four-foot pole microphone at a grass-covered site.

Moving next to a description of the Volpe Center, Read explained that the U.S. DOT Volpe is situated organizationally within the Office of the Secretary of Transportation. While Volpe's multidisciplinary subject matter experts number around 1,500, Volpe Acoustics is a smaller team that primarily supports the FAA's Office of Environment and Energy (AEE), but also works with other U.S. DOT transportation agencies (e.g., FHWA, FRA, etc.) as well as state and municipal governments.

For more than 40 years, Volpe Acoustics has continually supported AEE's aircraft noise certification efforts. As specified in FAA Order 8110.4C, Volpe performs audit validations of noise certification measurement and analysis instrumentation, methodologies, procedures, and software developed or used by applicants for aircraft noise certification under 14 CFR Part 36.

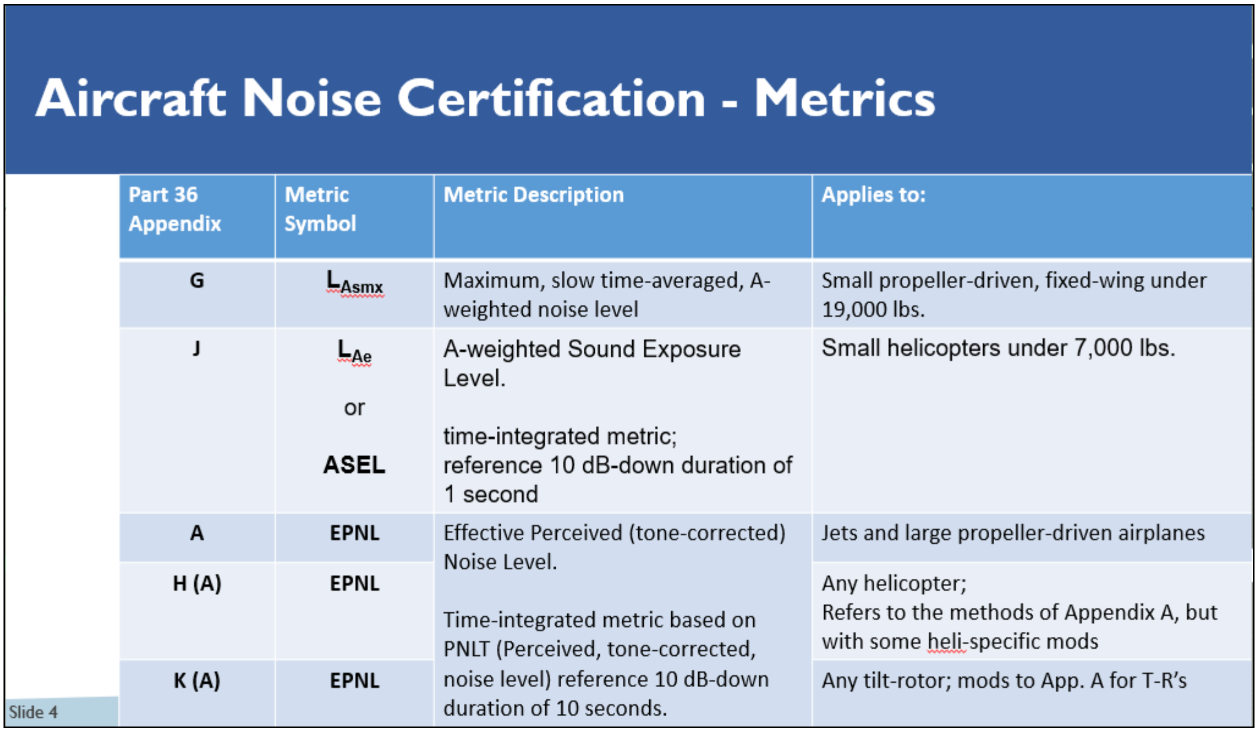
Focusing on Volpe's unconventional aircraft noise research program, Read presented the wish list of qualities for certification-compatible noise data in Figure 11-6. For example, primary data should be in the form of audio recordings, suitable for re-analysis and useful as source stimuli for auralization experiments. As detailed in the figure, desired characteristics fall under additional categories such as measurement sites, flight operations, microphones, aircraft position data, and meteorological data.

The speaker stressed the need for research to carefully choose instrumentation to correctly characterize aircraft noise, pointing to Figure 11-7 showing the contrast in data between the use of a ground-plane microphone and a four-foot pole microphone.

Next, Read presented Volpe's recommendations for research to support noise certification of aerial mobility vehicles. For one example, Volpe recommends prioritizing human response testing and psychoacoustic analyses to determine the degree to which annoyance is related to characteristics perhaps not meaningfully quantified by conventional noise level metrics. This recommendation and several others are summarized in Figure 11-8.

The speaker concluded with some overarching points:

- Public acceptance of aerial mobility aircraft may depend on adequate management of noise via aircraft noise certification and use of appropriate metrics.
- Noise from these aircraft may exhibit annoyance effects substantially different from what the public has previously experienced.
    - The variety of configurations, propulsion systems, and other factors may require a new framework for classifying similar groups of aircraft and for determining appropriate noise certification procedures and specifications.
    - New rules, methods, limits, procedures, and even metrics may be required to address community noise from such aircraft.
- And finally, the biggest research gap seems to be the lack of representative noise datasets. Evaluating these datasets will be the next step in determining whether any updates are needed to the existing noise certification paradigm.



Part 36 Appendix	Metric Symbol	Metric Description	Applies to:
G	L_{Asmx}	Maximum, slow time-averaged, A-weighted noise level	Small propeller-driven, fixed-wing under 19,000 lbs.
J	L_{Ae} or ASEL	A-weighted Sound Exposure Level. time-integrated metric; reference 10 dB-down duration of 1 second	Small helicopters under 7,000 lbs.
A	EPNL	Effective Perceived (tone-corrected) Noise Level. Time-integrated metric based on PNLT (Perceived, tone-corrected, noise level) reference 10 dB-down duration of 10 seconds.	Jets and large propeller-driven airplanes
H (A)	EPNL		Any helicopter; Refers to the methods of Appendix A, but with some heli-specific mods
K (A)	EPNL		Any tilt-rotor; mods to App. A for T-R's

Figure 11-1 *Aircraft noise certification - metrics*

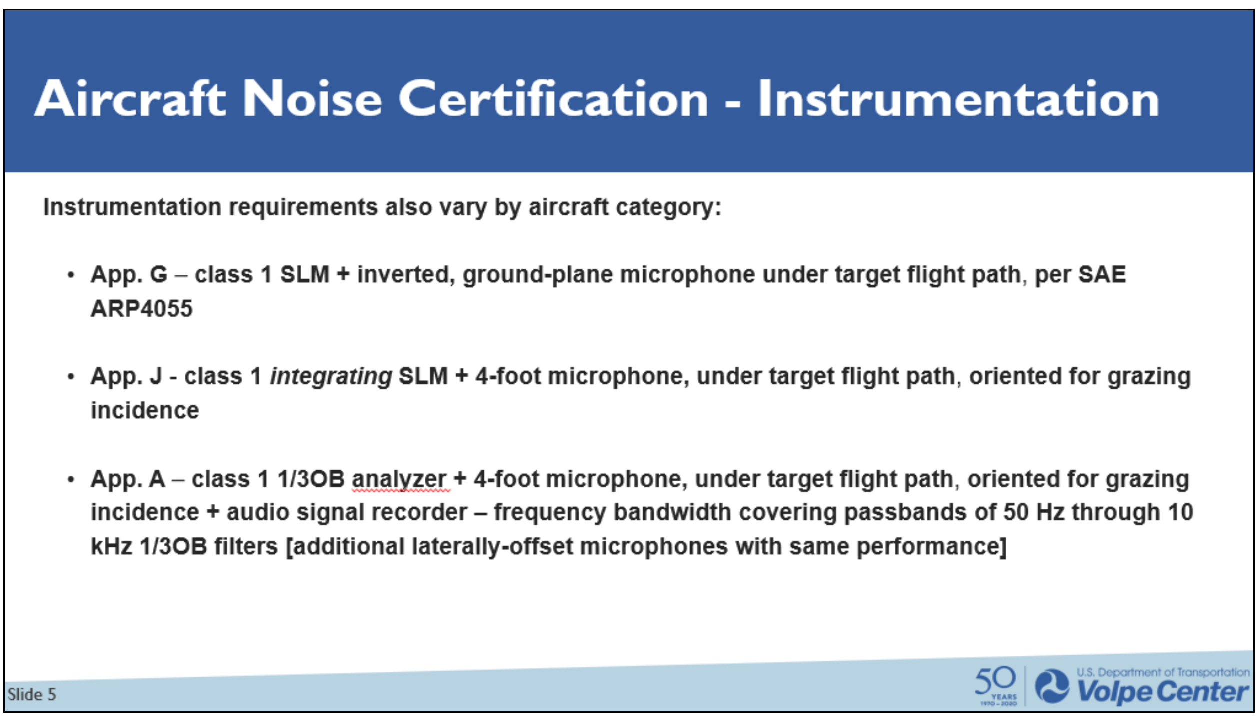


Figure 11-2 *Aircraft noise certification - Instrumentation*

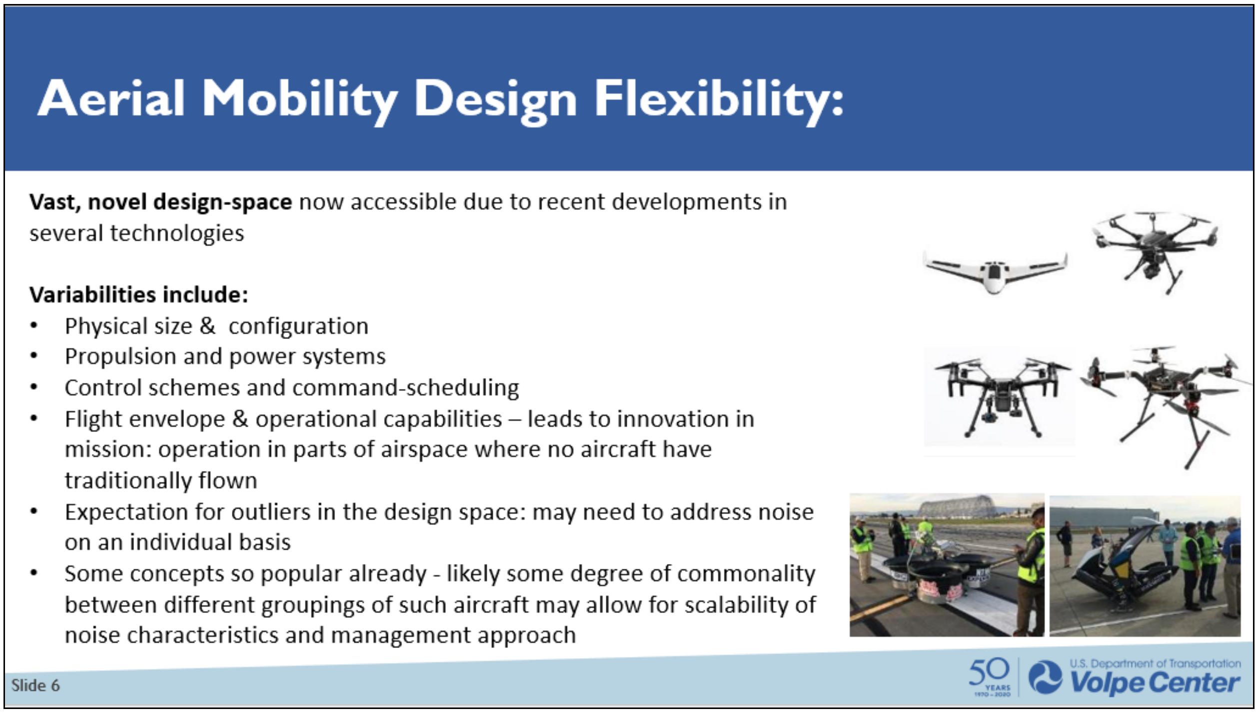


Figure 11-3 *Aerial mobility design flexibility*

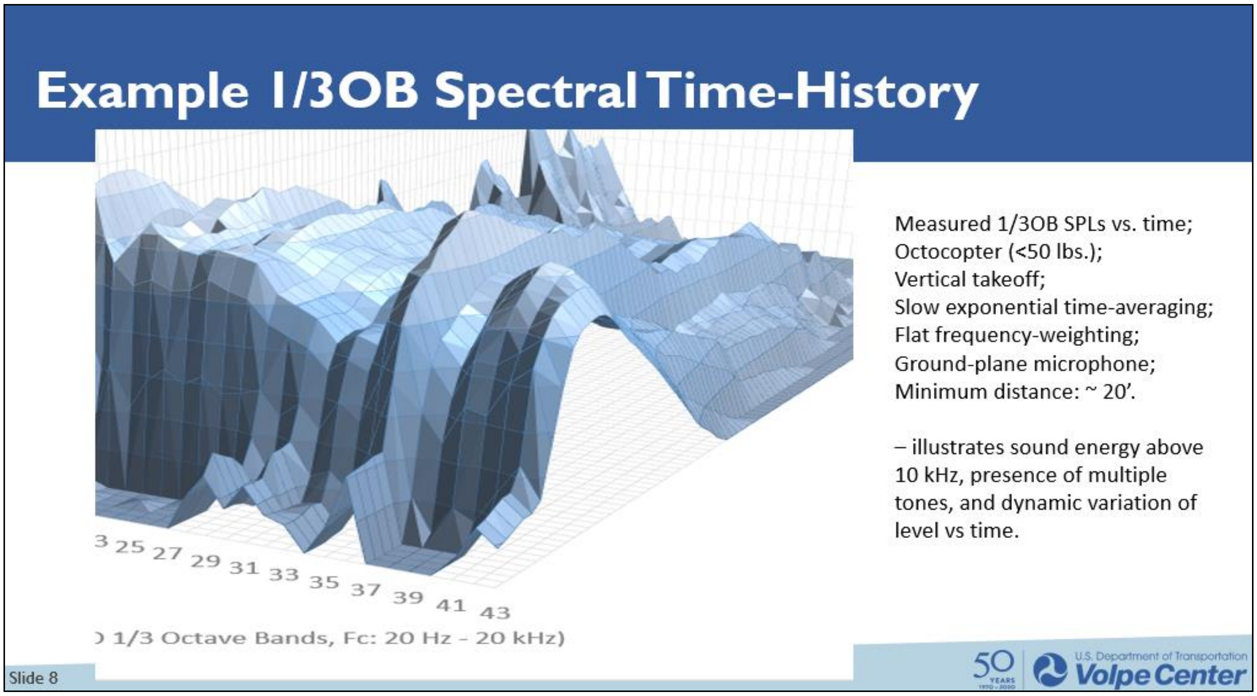


Figure 11-4 *Example of Multicopter 1/3 OB spectral time history*

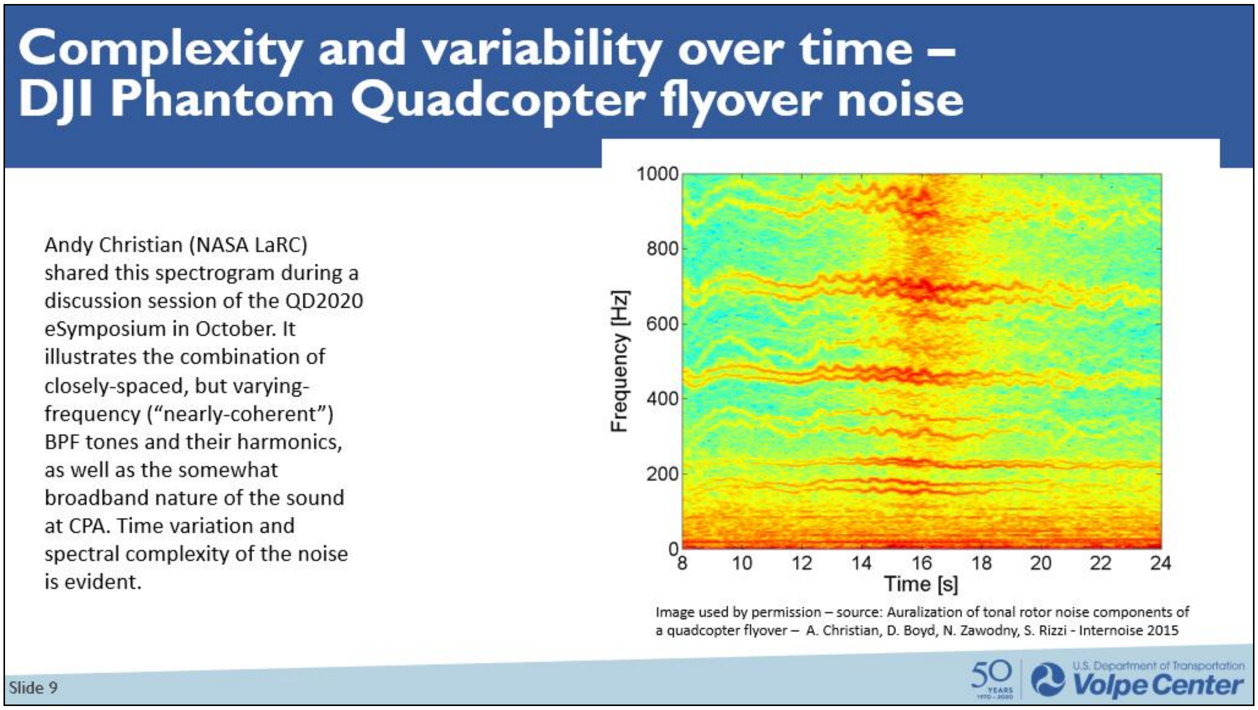


Figure 11-5 *Complexity and variability of quadcopter flyover noise*

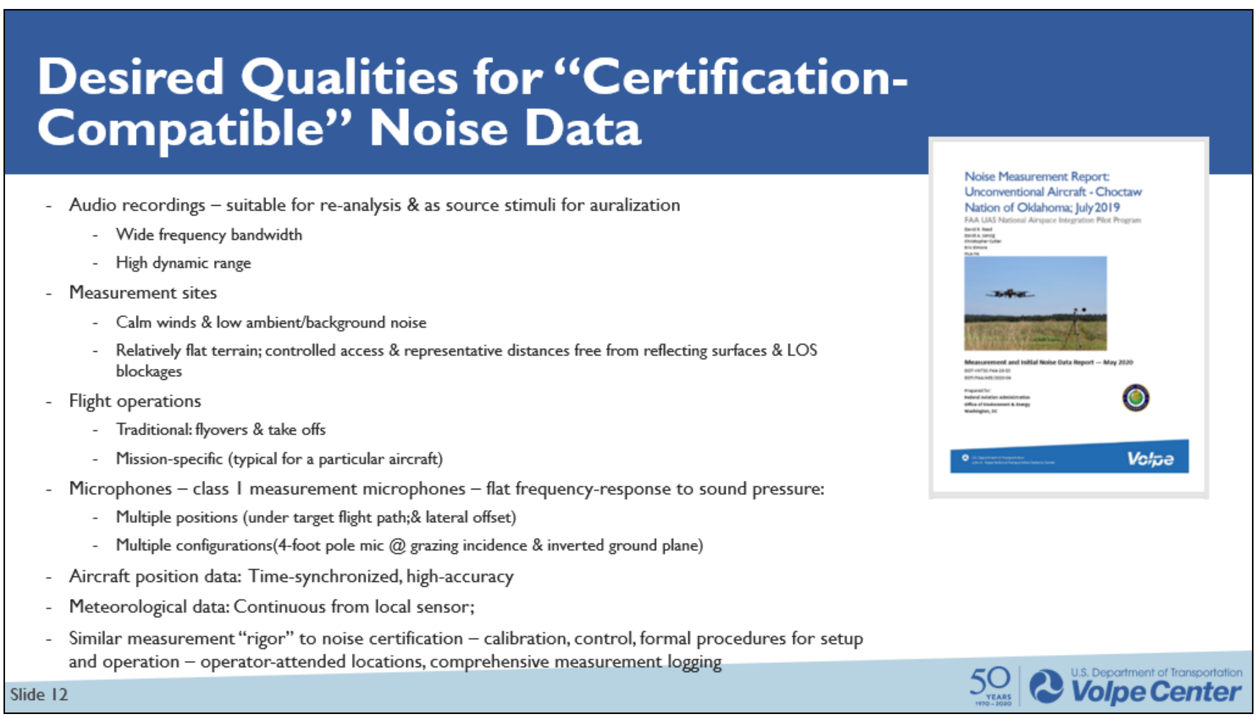


Figure 11-6 *Desired characteristics of noise data to support certification*

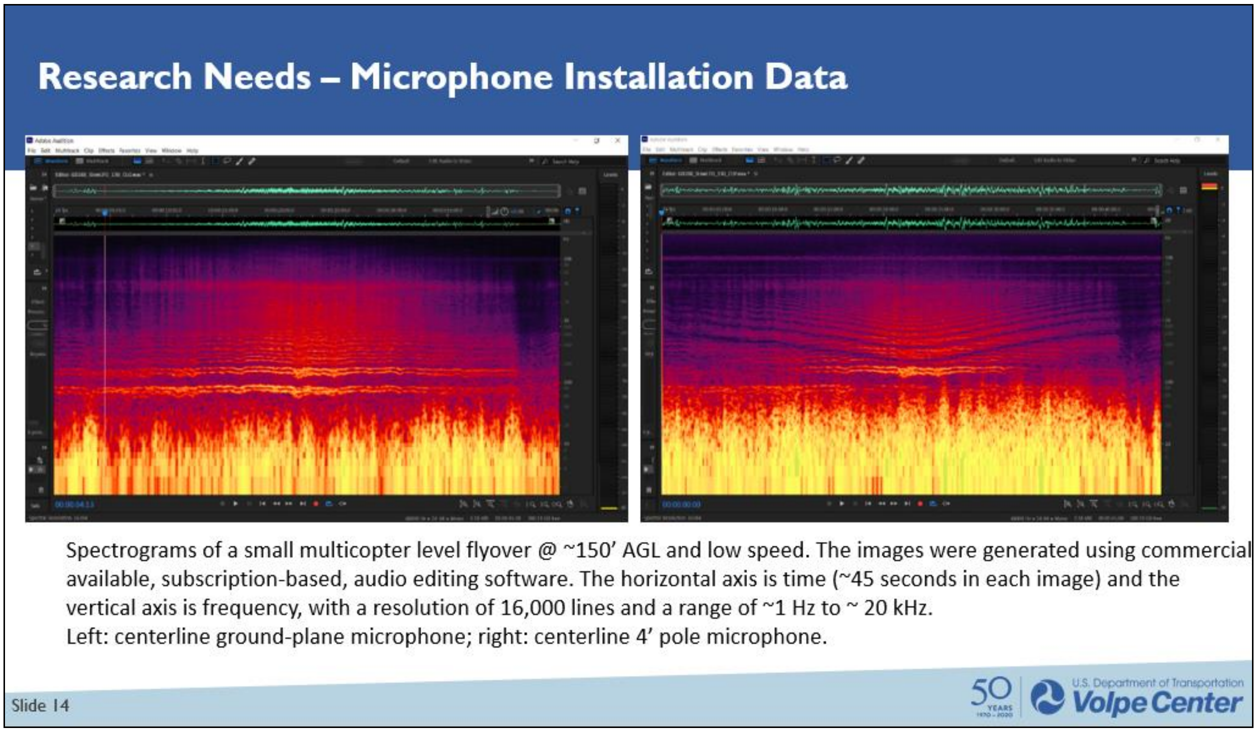


Figure 11-7 *Research needs: microphone installation data*

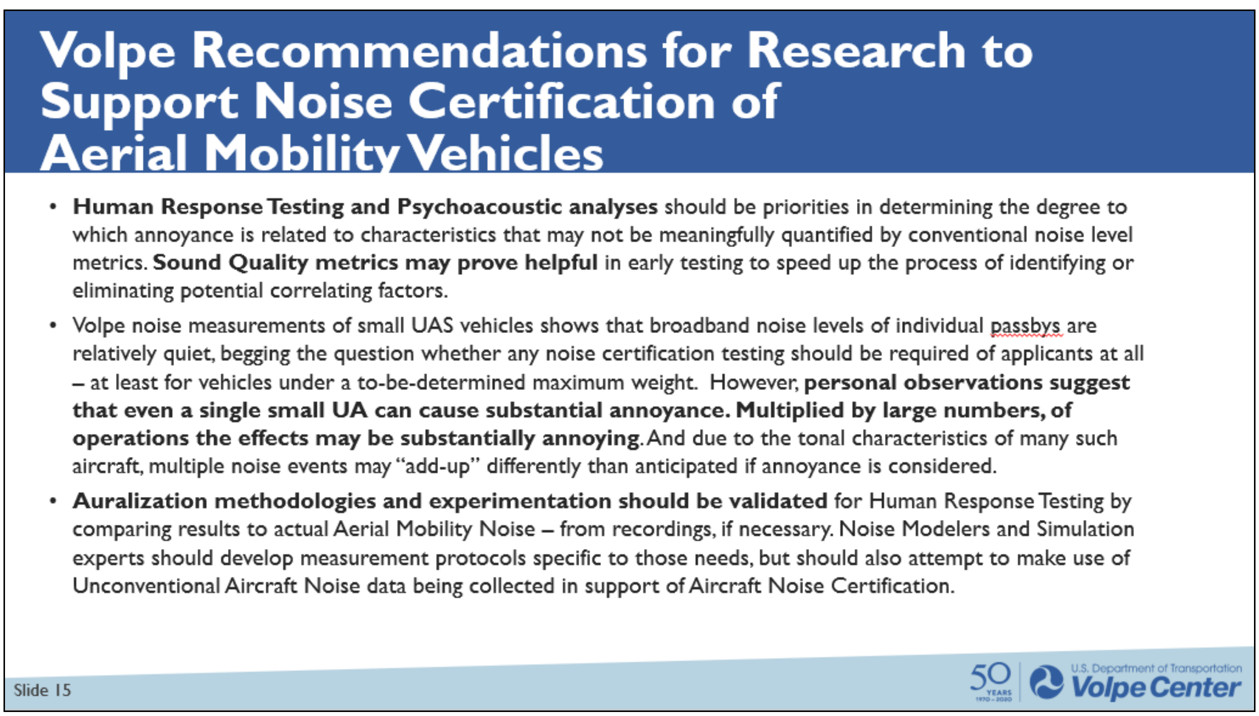


Figure 11-8 *Volpe recommendations for research to support noise certification of aerial mobility vehicles*

12. UAM Fleet Noise Assessments Using the FAA Aviation Environmental Design Tool

Stephen Rizzi—NASA

Current tools for evaluating community noise from aircraft offer promise for assessing noise from urban air mobility vehicles, but applying these current methods to UAM will require significant adaptations. NASA's Langley Research Center is working to assess the effectiveness of, and recommend needed adjustments to, these current tools. Initially, the group has focused on developing a methodology using the FAA's Aviation Environmental Design Tool, or AEDT, which has required them to tackle complex challenges arising from the lack of an aircraft noise and performance model for UAM.

In this second workshop presentation by Stephen Rizzi, the Senior Researcher for Aeroacoustics at the NASA Langley Research Center discussed NASA Langley's use of the FAA Aviation Environmental Design Tool (AEDT) for conducting UAM fleet noise assessments. In particular, Rizzi's presentation covered topics including motivation and approach, operational state determination, calculation of noise-power-distance (NPD) data, modeling approach, generation-1 assessment, and additional work planned in this area.

Out of the box, AEDT is not fully equipped to handle UAM community noise studies, Rizzi explained, given the tool's lack of an aircraft noise and performance (ANP) model for UAM vehicles. Addressing this gap requires user-supplied NPD data and the use of fixed-point flight profiles. In its work, NASA Langley considered a representative route case from a NASA air traffic management simulation using 16 routes around Dallas-Fort Worth and two reference concept vehicles—a NASA Revolutionary Vertical Lift Technology (RVLT) Project quadrotor and an RVLT lift-plus-cruise [L+C] vehicle.

The first step toward understanding UAM community noise is determining each relevant vehicle's operational state, as reflected in a plot of air speed versus climb angle such as the one shown in Figure 12-1. This operational state is what dictates noise, Rizzi stated. Analysis of the most frequent occurrences of vehicle flight envelopes reveals 42 unique operating states for the quadrotor and 44 for the lift-plus-cruise vehicle.

The speaker next discussed the two modes of AEDT operation: fixed-wing mode and helicopter mode. Important facts about each of these are summarized in Figure 12-2. Among them: For fixed-wing mode, source directivity is applied using a dipole radiation model applied in the noise fraction adjustment for exposure metrics; and for helicopters, source directivity is specified either in dynamic mode as 0±45 degrees, or static mode by helicopter-specific directivity.

In its examination of UAM vehicle noise, Rizzi's team relied on a "fixed-point" flight profile using fixed-wing NPDs that bypass AEDT performance models. The database links noise (L_{AMax}, SEL, $PNLT_{Max}$, and EPNL) to the vehicle state and distance to the observer. Further detail in this context is provided in Figure 12-3.

After providing further particulars of Langley's NPD data computation, Rizzi discussed the bar chart in Figure 12-4, which reflects the quadrotor's sound exposure level (SEL), at a given distance for all flight conditions. The speaker spotlighted the significant variation in SEL depending on the operating condition. Similar bar charts exist for L_{AMax}, $PNLT_{Max}$, and EPNL, he noted.

Next, Rizzi discussed the modeling approach, as summarized in Figure 12-5. He stated that, in addition to the calculated NPD data, a set of profile points define the aircraft's distance along the track, altitude (Z), speed, and thrust set from start to finish. Within AEDT, the calculation combines this profile and track point data.

Overviewing this work so far by NASA Langley, the presenter stated that his team has developed a means of performing UAM community noise assessment using the AEDT fixed-point flight profiles, identifying limitations along the way that will be examined in the group's Generation-2 assessment. The group also developed an automated method for analyzing routes and developing track and profile data, as well as an automated means of generating large, scalable AEDT inputs. Rizzi noted that the results shown are not claimed to reflect expectations for UAM operations in the Dallas-Fort Worth area, for various reasons. Rather, the intention here was to develop and demonstrate a viable methodology for assessing community noise impact of UAM vehicles using AEDT

The speaker concluded by discussing the Langley Research Center's plans for additional work in this area, which are summarized in Figure 12-6. Goals include improving analysis fidelity while investigating the use of helicopter mode near vertiports to capture lateral directivity. Data will also be inputted directly into the AEDT database for ease of use.

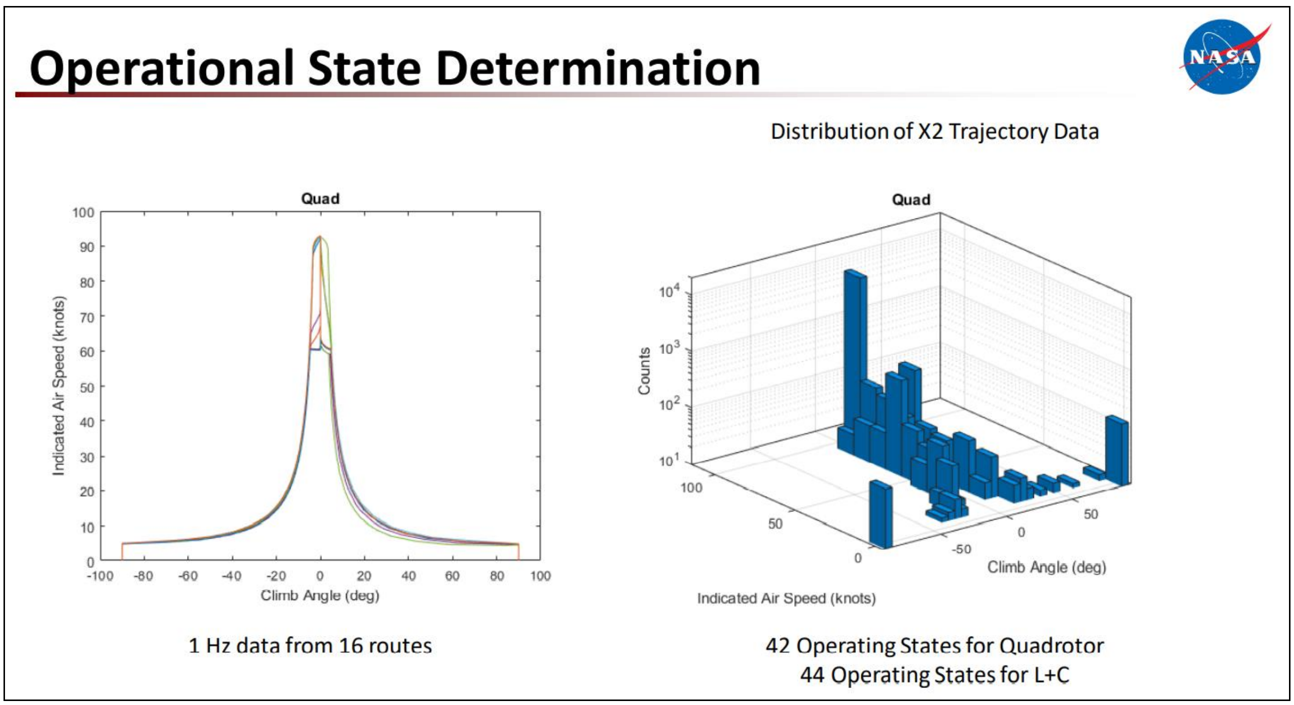


__Figure 12-1__ Determining operational state toward assessing noise

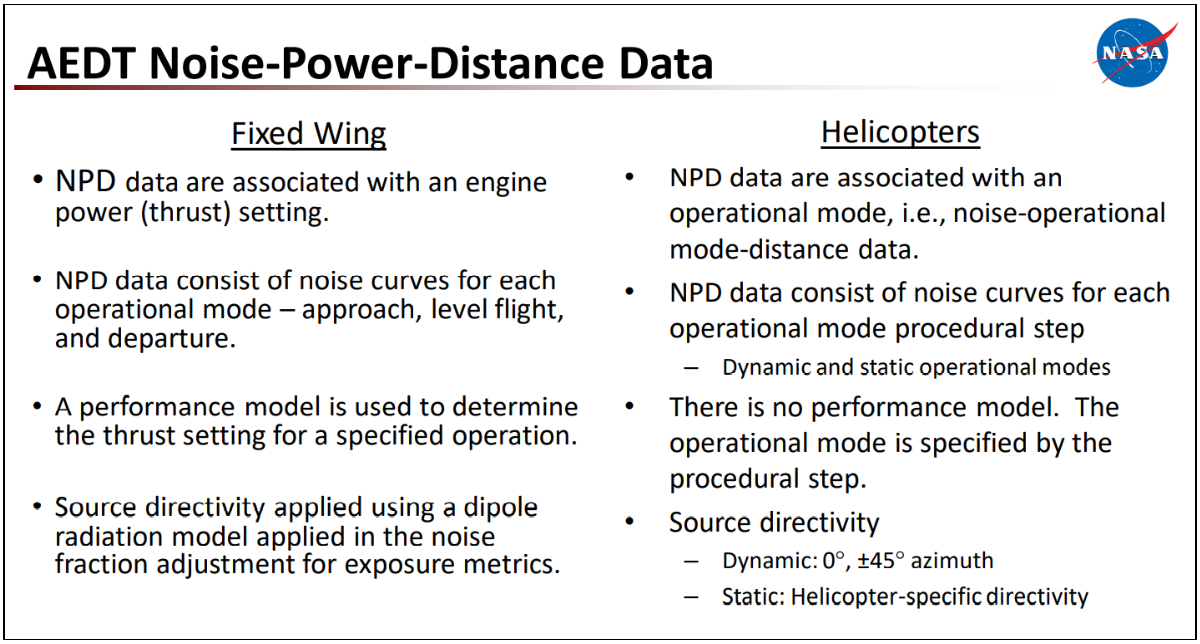


Figure 12-2 *AEDT Noise-Power-Distance data: fixed wing and helicopters*

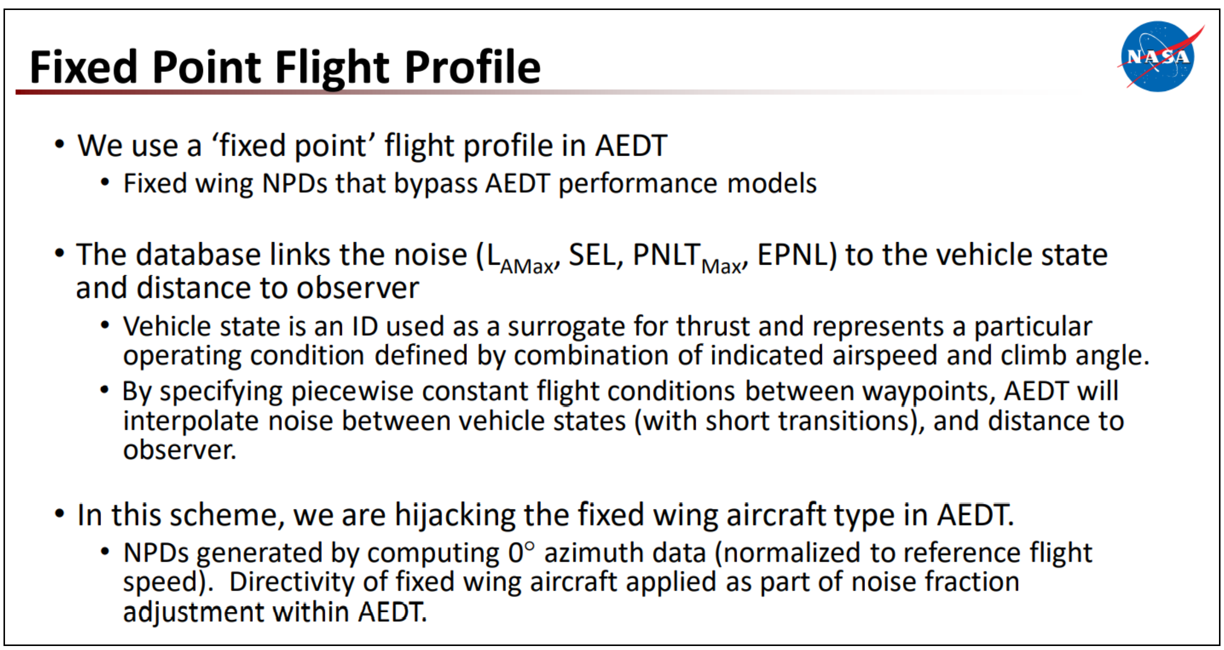


Figure 12-3 *Use of fixed-point flight profile in AEDT*

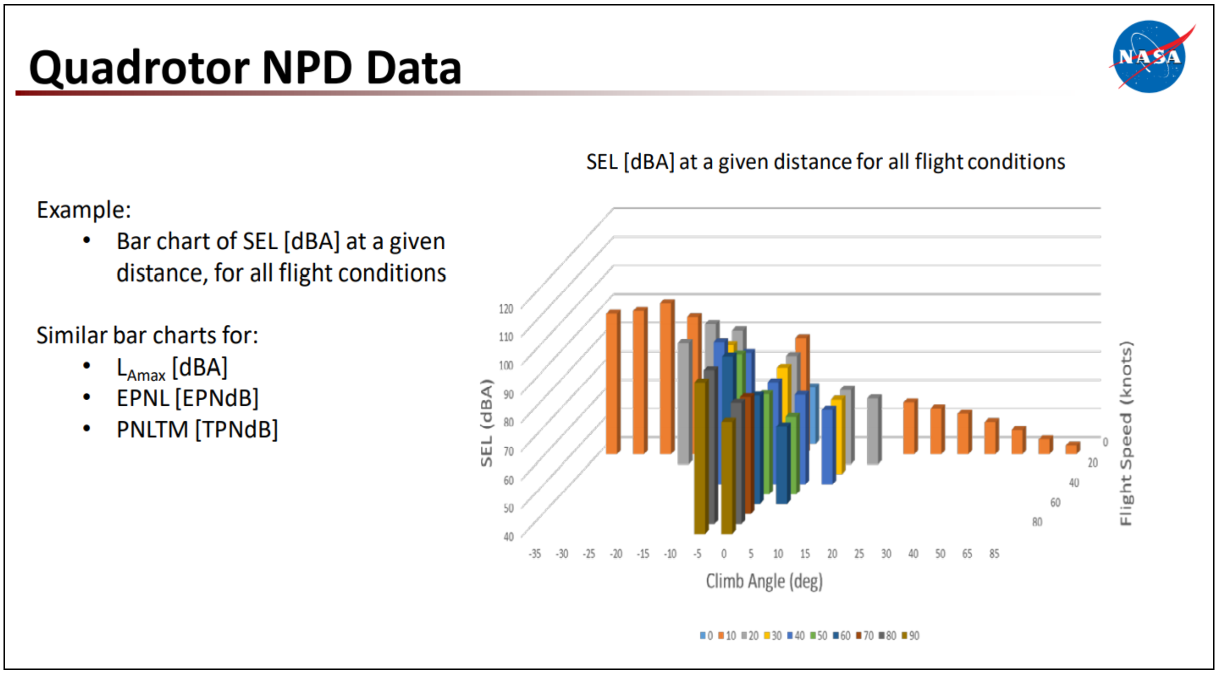


Figure 12-4 ***Quadrotor*** *Sound exposure levels vary based on operating conditions*

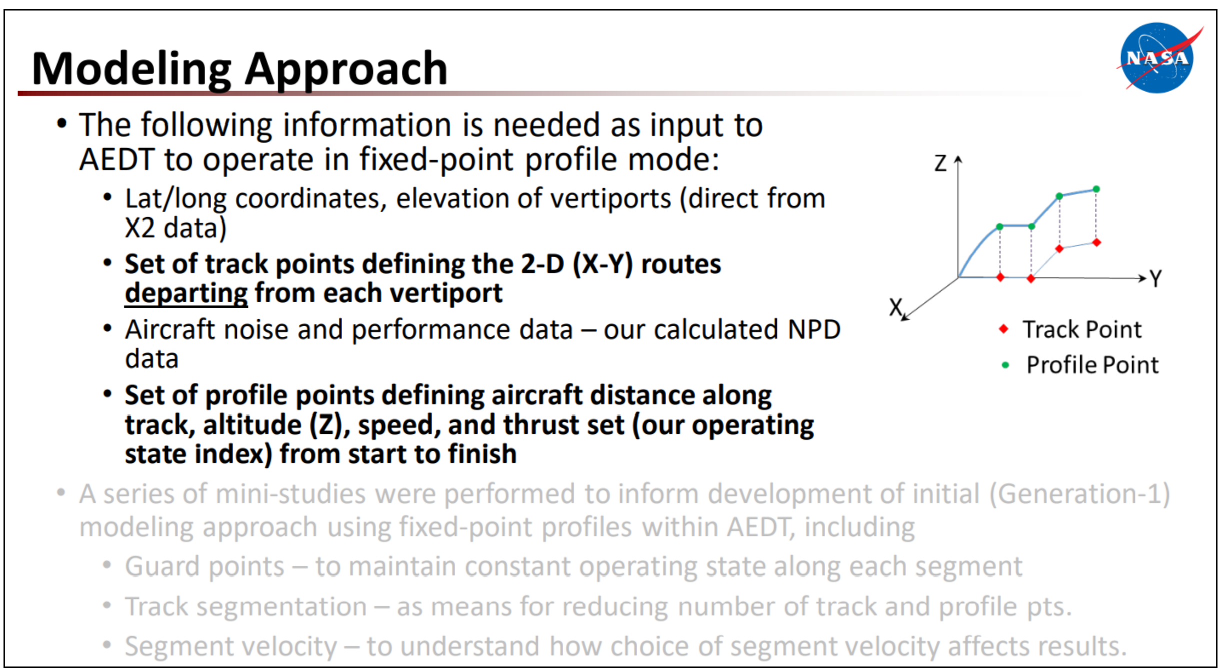


Figure 12-5 *Modeling approach: required information*

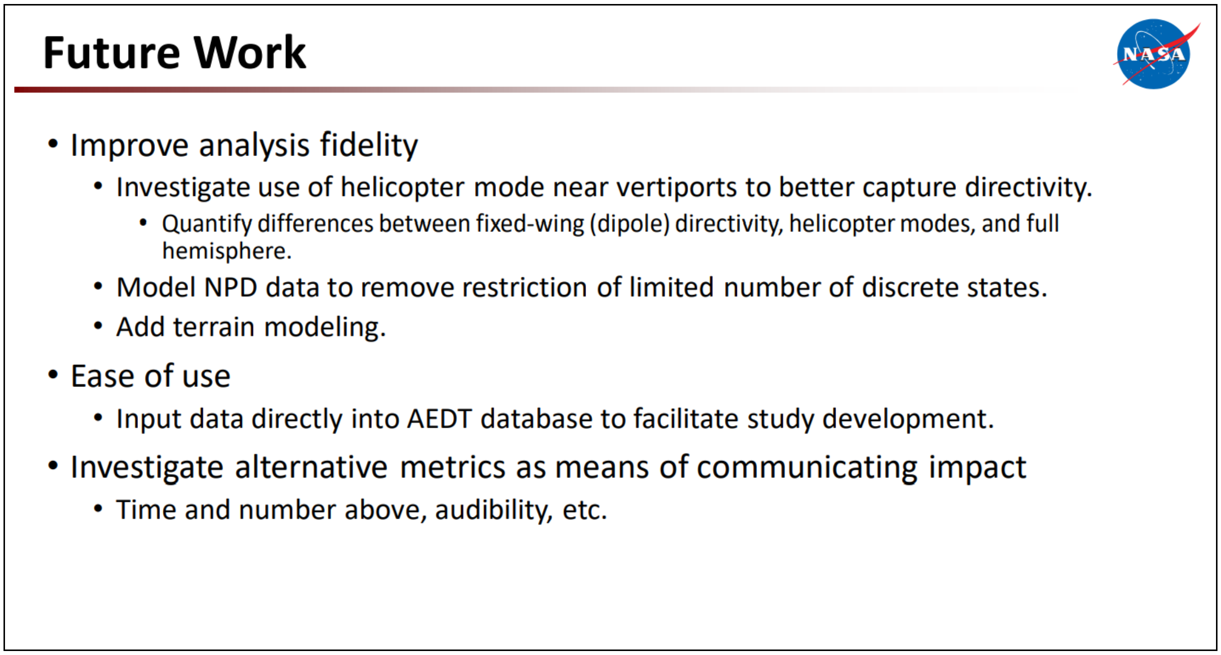


Figure 12-6 *NASA Langley future work: assessing UAM fleet noise using AEDT*

13. The Future of the Air Cargo Industry

Stephen Alterman—Cargo Airline Association

Transformative changes are underway, and more are in store, for the huge and growing air cargo industry. Drones are already handling the so-called "last mile" of product delivery, and urban mobility vehicles—either autonomous or piloted—are expected to play an ever-increasing role in this cargo market. Among other challenges, the industry is eyeing improved environmental friendliness—including decreased noise—for its aircraft, through reliance on sustainable fuels, efficient routes, and eventually even electric aircraft.

Stephen Alterman, president of the Cargo Airline Association, shared his expertise about the "daunting" challenges faced by the air cargo industry—challenges magnified by the fact that industry moves much faster than the U.S. government that regulates it. So the industry continues its work on new products and innovations, prepared to implement advances once the federal government gives its nod.

CAA represents all U.S. cargo carriers, including many well-known companies such as FedEx, UPS, DHL Express, and Amazon, and some heavy hitters that are less widely known such as Kalitta Air, ABX Air, and Atlas Air. Associate members include airports with significant air cargo presence, which represent important operational partners.

The air cargo industry is made up of a complex combination of those that participate in the air cargo supply chain, including air carriers, air freight forwarders, airports, shippers, screening facilities, and canine screeners, among others. The speaker anticipates that future entrants will include commercial drones along with other urban air mobility vehicles that will become a part of the air cargo supply chain moving forward.

Alterman next gave attendees a sense of the size and growth of his industry, which globally employs more than 1.5 million people and flies about 1,000 all-cargo aircraft. Boeing has forecast that, in 20 years, air cargo revenue expected in ton kilometers will have doubled. In 2019, e-commerce was 14 percent of retail sales—double the 2015 percentage. "Then came the pandemic," with an explosion in e-commerce to a level not expected for some three to five years. "These products that are ordered online are invariably delivered by one of our members," Alterman stated, leading to exponentially greater demand. Given this demand, and the fact that cargo carriers also distribute business-to-business products as well as medical supplies, flights have reached nearly 100 percent capacity, according to Alterman, who highlighted the approaching challenge of COVID-19 vaccine distribution.

Large cargo aircraft such as the Boeing 747, 757, 767, and the Airbus aircraft are supplemented by a fleet of smaller regional aircraft that connect smaller communities to the national network. Whereas the cargo industry by-and-large used to operate older, noisier, and less environmentally friendly aircraft, the industry currently operates new aircraft alongside those older ones converted from passenger service. Given the long-term nature of industry investment in new aircraft, the percentage increase of new aircraft in the fleet mix is likely to continue into the foreseeable future.

Next, the presenter spoke about automation, as addressed in Figure 13-1. Alterman explained that automation is currently focused largely on the last mile of product deliveries, with urban air mobility vehicles such as drones picking up deliveries where the legacy aircraft routes end. Deliveries using drones already occur—UPS is delivering medicines to nursing homes using drones, for example. Most Cargo Airline Association members are becoming FAA-certified to use drones in commercial deliveries. Alterman expects urban air mobility vehicles—whether autonomous or piloted—to increasingly play a role in product deliveries. So far, interaction is lacking between larger delivery aircraft operators and those undertaking the "last-mile" deliveries, Alterman said, pointing out that more interaction will be required for seamless deliveries as demand rises. With increasing automation and on the way to more complete automation, the air cargo industry is examining a possible switch from today's norm of two-pilot cockpits to single-pilot aircraft, though the pilot unions "violently opposed" the prospect in the past and a related bill failed to become law.

Moving to the subject of the environment, as addressed in Figure 13-2, Alterman stated his association strongly supports the use of sustainable aviation fuels, made from materials besides petroleum. The fuels are for now prohibitively expensive, but the air cargo industry is working to increase the supply of appropriate fuels and in turn lower the price.

The new aircraft used by the industry are more fuel-efficient, which translates into greater environmental sustainability. Also, more efficient routes being created by the industry, in collaboration with the FAA, mean less fuel use, less cumulative noise, and enhanced air quality. The downside of new routings: They have attracted complaints from those people whose noise exposure has increased, even as aggregate noise had significantly decreased. The FAA has improved its response to these community complaints in recent years with transparent communication that helps people understand the benefits of the new routes and participate with FAA on improvements. The cargo industry works with airports in addressing these types of community concerns.

In response to a question from Gregg Fleming, Alterman explained that, in the context of drone noise, the Cargo Airline Association has not been involved with community engagement, but that drone and urban air mobility operators themselves work with the community to address concerns. The final development Alterman discussed with the promise of achieving environmentally friendly aircraft was electric aircraft. Smaller aircraft are likely to appear on the scene sooner than larger electric ones.

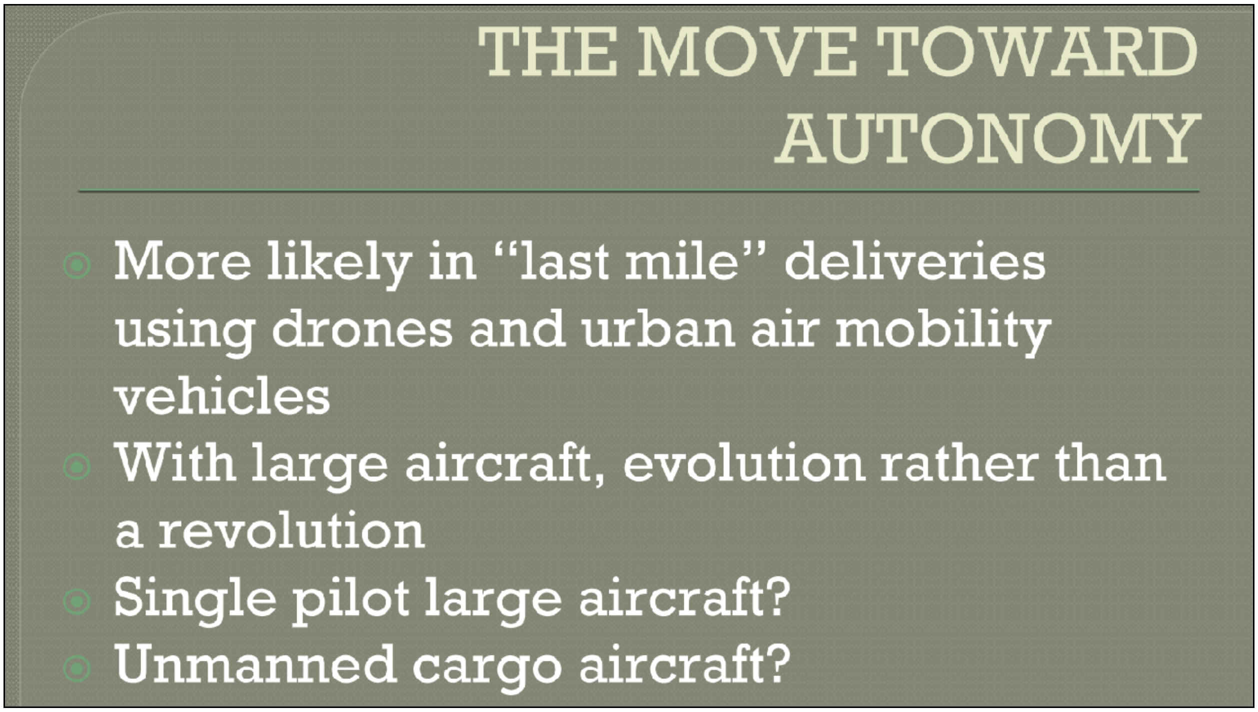


Figure 13-1 *Toward vehicle autonomy*

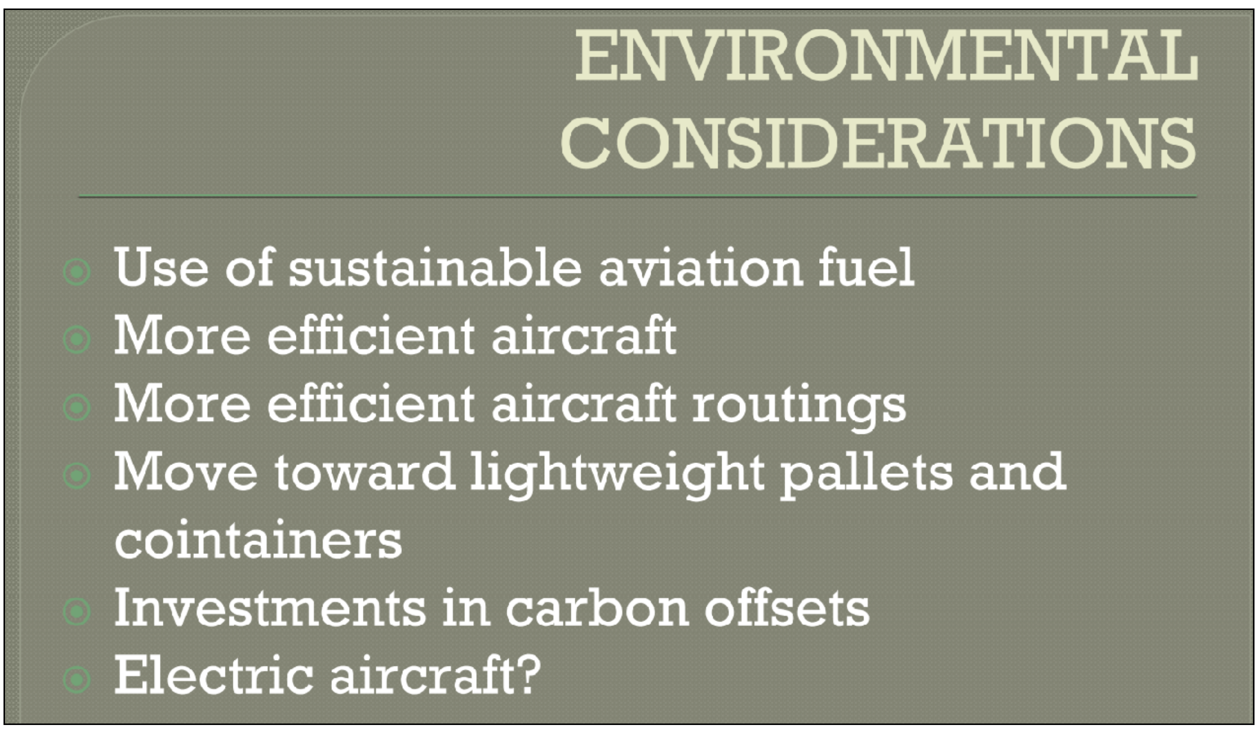


Figure 13-2 *Toward more environmentally friendly cargo aircraft*

14. Why Is Predicting Audibility So Hard?

Andrew Christian—NASA

Despite the challenge it presents, arriving at an audibility prediction provides a needed foundation for assessing annoyance from, and understanding community response to, urban air mobility noise. NASA has faced various hurdles in its pursuit of audibility models to foretell UAM-associated annoyance.

In this first of his two workshop presentations, NASA Langley psychoacoustics researcher Andrew Christian shared his views on the difficulties associated with predicting audibility. Much of the aerial mobility-related work at NASA in the couple of years preceding the current workshop was focused on creating models of audibility to aid in the prediction of annoyance, he said.

Christian introduced two rules of thumb from the literature regarding the link between annoyance and audibility:

- When sources of noise are sufficiently prominent over the ambient noise level, there is no strong effect of the ambient level on annoyance; and
- When sources of noise get close to the ambient noise, a masking effect occurs that affects annoyance in ways unexplained by the sound reduction of the source itself.

While sound reduction clearly results in less annoyance, at some point, there is also a doubling benefit in terms of diminished annoyance, as sound decreases and ultimately is turned down to a point where it melds with the background and people can no longer hear the noise. Research is focused on trying to formulate an approach for figuring out when the double-benefit kicks in. With respect to UAM, this compounded benefit could be seen when the noise level fades into the soundscape.

The presenter introduced the concepts of the "signal" that is being listened for and the "masker," as addressed in Figure 14-1. The goal is to predict the probability that a listener heard a signal in the presence of a masker. If the signal is inaudible, it is said to be masked. Researchers are seeking an audibility prediction algorithm to provide a statistical measure of audibility based on a recording of the two sounds.

The first steps toward such an algorithm can be based on the ear's role as a transduction mechanism. The ear can be considered to be a bank of bandpass "auditory filters," with the signal and noise filtered separately by this bank. The filters have complicated shapes, which change with frequency and absolute level (nonlinearities).

The simplest approach for attempting to predict audibility is by using a "power spectrum" model, as explained in Figures 14-2 and 14-3. The sound power of a signal is computed using each of the filter outputs. Then, disregarding the further details of the signal, the filter with the highest signal-to-masker ratio is identified. Empirical methods can then be used to relate the ratio to a prediction of audibility.

Additional problems remain to be untangled, such as what happens when signals occupy more than one filter. Regardless of how these issues are solved—and there is no best way—"you wind up with a lot of different flavors of this kind of power spectrum concept of masking," the presenter stated. The power spectrum model can help predict a large amount of empirical data for very fundamental sounds—with, for example, up to a few tones of "moderate" length, in a stationary broadband noise masker.

But complications arise in the context of realistic signals, Christian pointed out, stemming from the fact that auditory filters in the ears are not simply power detectors. They are transduction mechanisms that generate neural firing codes, and the brain is left to determine, from the information it gathers from this auditory nerve, whether sound is there or not.

Humans are known to use various types of information in audibility that are not predicted by the basic power spectrum model. These include the temporal envelope; the spectral envelope; spatial cues (when the signal and the masker are well separated spatially, less of a masking effect occurs compared to when they are co-located); and also non-auditory, or cognitive, factors. Christian emphasized that a sound level meter-like device with a signal and a masker and a single microphone cannot be made to measure sound in this way. "This is the crux of the presentation," he said. "This is why audibility predictions are so difficult."

So, while attempts are made to generate more complete models of the auditory system, none is mature or accessible enough to be used for noise assessment. Instead, the presenter said, the best course may be to try and bound the set of applicable signals and maskers: such as UAM-type vehicles and urban soundscapes; calibrate simple models to empirical results to eliminate bias; and quantify the remaining uncertainty. Data is key, then, to provide a more complete picture and more confident audibility predictions.

Even after arriving at a prediction of audibility with uncertainty sufficiently quantified, predicting annoyance remains as the next challenge. The major question in this context: Is it necessary to just hear a signal or must it be so loud that it draws your attention? And what rises to the level of annoyance—when a sound interferes with people talking, for example, or stops them from a quiet task such as reading? The concept of such disturbance has been referred to in the literature by terms such as "noticeability" and "intrusiveness," whereas a sound that falls short of such interference is said to "blend." These issues must be assessed before the model can be a useful, end-to-end annoyance prediction model..

The presenter concluded his presentation with some overarching points:

- Predicting audibility is difficult, but likely necessary for the assessment of noise-induced annoyance from UAM.
- Many complicating effects may contribute to the audibility of aerial mobility vehicles operating in already-noisy environments.
- UAM audibility models have not yet been fielded, due to a dearth of data and the inability to perform psychoacoustic tests.

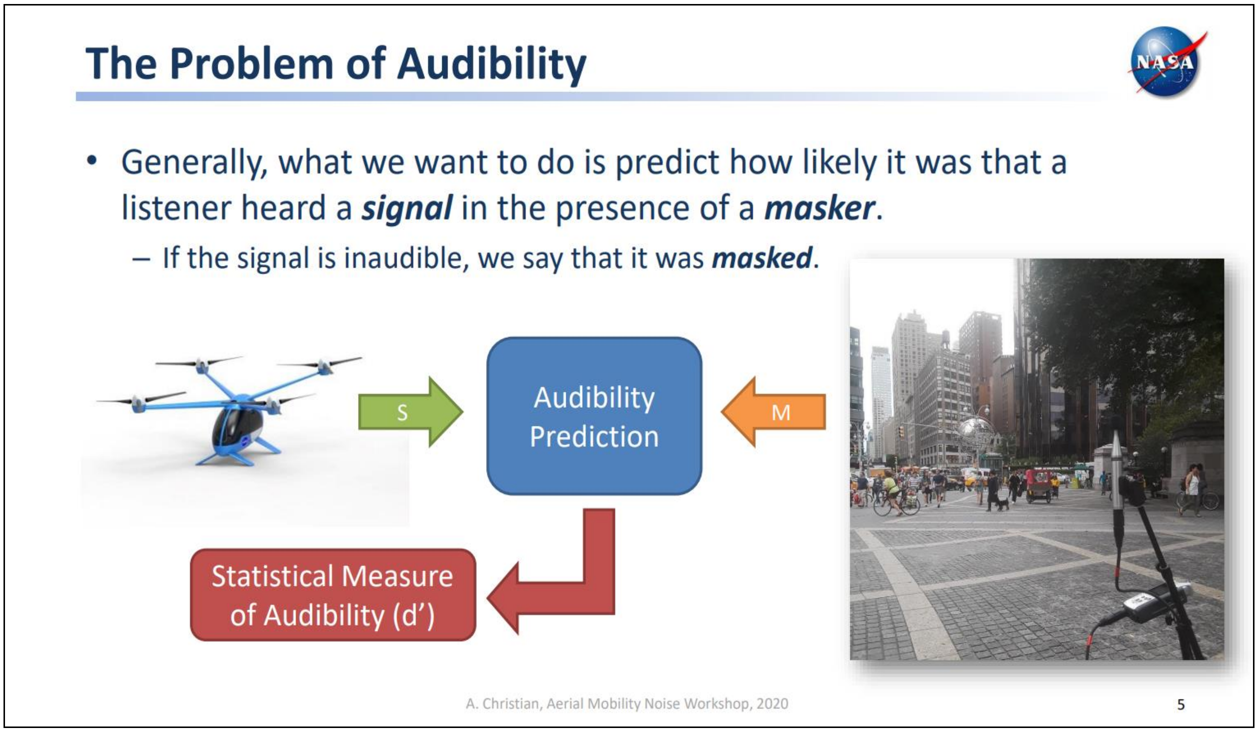


Figure 14-1 *The problem of audibility*

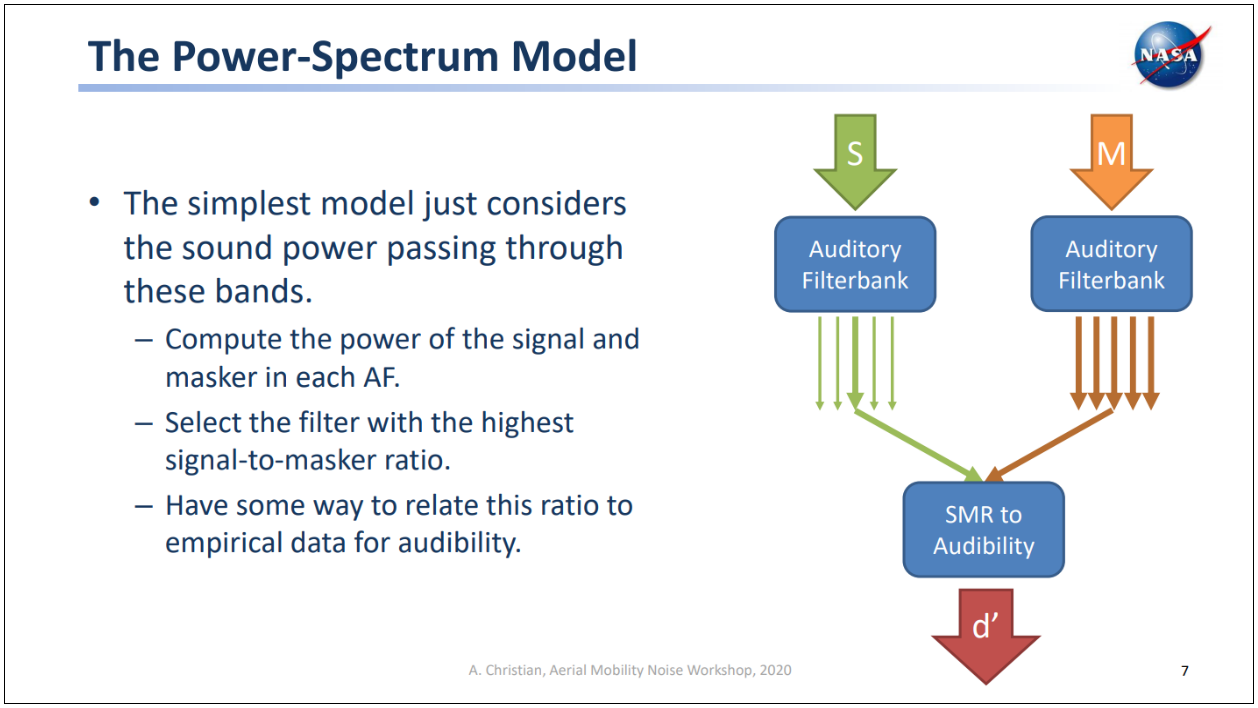


Figure 14-2 *Power spectrum model for predicting audibility (1 of 2)*

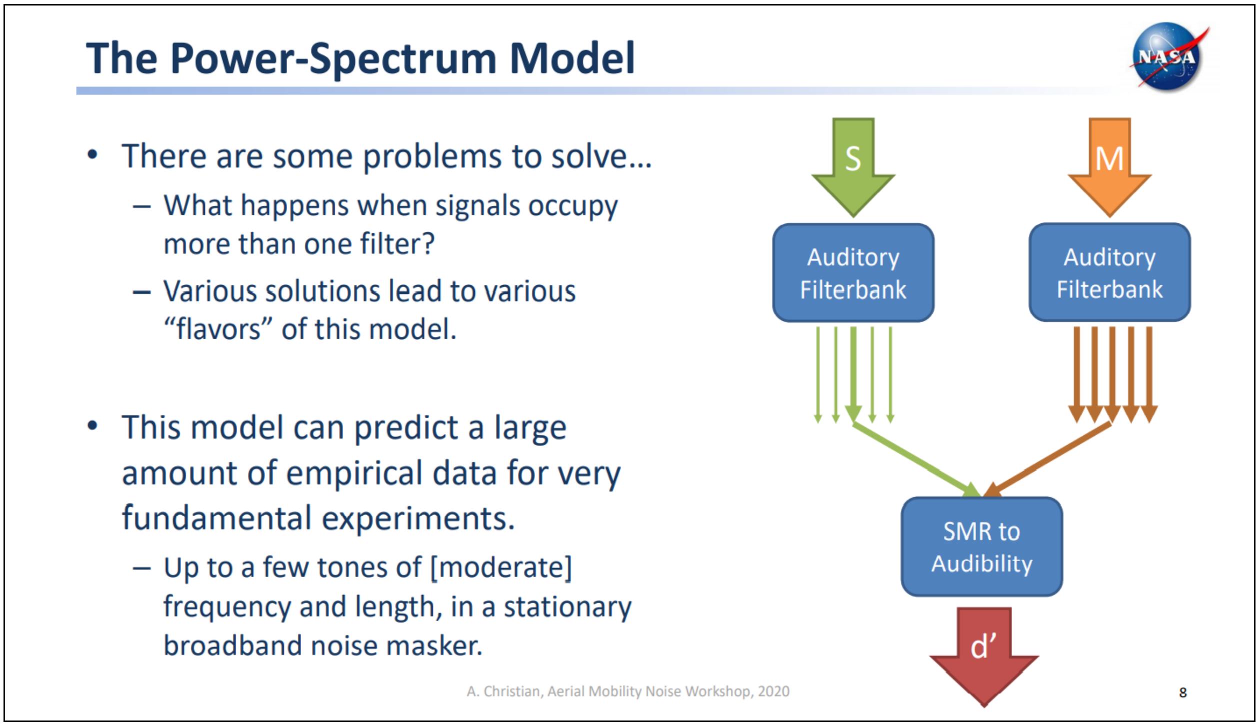


Figure 14-3 *Power spectrum model for predicting audibility (2 of 2)*

15. Sound Quality and Its Potential Influence on the Acceptability of Noise from Aerial Mobility Vehicles

Patricia Davies—Purdue University

While current noise metrics relate largely to sound level, various additional characteristics are likely to influence people's response to noise from aerial mobility vehicles. A fuller understanding of people's qualitative concerns could provide a meaningful complement to quantitative metrics. And consideration of both types of measurements—especially early on during the vehicle design process—could represent important progress toward UAV sound optimization.

Purdue University professor of mechanical engineering Patricia Davies shared her expertise about how various characteristics of sound could influence people's acceptance of noise from aerial mobility vehicles. For example, how annoyed will people be by certain kinds of sounds? As a footnote, Davies mentioned that noise can also influence people's perceptions of how well a vehicle or other machine is working.

Davies introduced sound attributes, beyond sound level (how loud the sound is), that affect sound quality and influence people's perception of sound. While most currently relied-upon metrics relate to sound level, additional sound attributes include:

- *Spectral balance*. This attribute goes to sharpness and heaviness—i.e., high-frequency content and low-frequency content, respectively.
- *Tonalness.* Tone penalties exist in aircraft certification and environmental noise.
- *Variations.* Alarm sounds often have trackable variations, or fluctuations, Davies stated, noting that fast fluctuations in levels give sound a very rough, unpleasant character and that people are sensitive to fluctuations around four times per second. "If something is always 'prodding' you to pay attention to it," Davies said, "you may have a different reaction to that versus something that may be a bit louder but does not have such distinct characteristics."
- *Impulsiveness.* This term refers to a sound of short duration.
- *Harmoniousness.* This issue of how an item's various components interact in terms of sound has been a consideration in the car industry, for example. She highlighted the Miata's design that brought various parts together "musically."

The presenter stated that the following sound characteristics beyond sound level may play an important role in people's judgment of UAM vehicle sound:

- *Presence of tonal components.*
- *Variation of tonal components*—frequency modulation and potentially amplitude modulation, for example.
- *Effects from combinations of noise sources*—different rotating parts, each of which makes a sound that might sound unobjectionable, can combine to create a beating phenomenon, loudness fluctuations, and sometimes very rough sounds, Davies said.
- *Impulsiveness.*

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Developments in sound quality metrics have been focused on models of the strength of fundamental sound attributes, as depicted in Figure 15-1, and principal component analysis has been used to identify fundamental sound attributes that people notice. People might be hearing a combination of attributes, and much remains to be elucidated about how certain quality metrics, which measure characteristics such as sharpness, heaviness, or impulsiveness, can be translated into models that predict people's descriptions of sound. Meanwhile, Davies cautioned against relying on assumptions and supports steps being taken to "actually talk to people and learn about what aspects of noise or sound are concerning to them." Davies went on to note that differences in sound pleasantness are likely to figure into differences in annoyance along with other factors.

Next, the speaker addressed why sound quality projections are even needed. Predicting the sounds machines will make, and answering questions such as "how would this vehicle sound in its environment?" would allow noise to be considered as an integral part of the design process rather than as an afterthought, she said. These sound quality predictions complement other approaches to understanding sound, Davies stated, such as sound evaluation using subjective testing and community surveys.

Standardization of sound quality metrics has seen progress over the years. Problems still exist in terms of the application of these metrics to complex sounds. UAVs present challenges in terms of factors such as tonal components and continually changing frequency, she explained. Figure 15-2 lists some outstanding challenges in this area of fundamental sound quality metrics, which for example have promise in supporting development of metrics to predict the strengths of pounding, fluttering, and the other listed characteristics.

Sound quality also plays a role in whether people continue to be annoyed by certain sounds or acclimatize, Davies pointed out. Impulsive and fluctuating sounds grip our attention and impede acclimatization, she said, providing examples of sounds with mainly broadband components that are easier to become accustomed to, such as some heating, ventilation, and air conditioning noise where tones are not noticeable. Figure 15-3 lists some important attributes for consideration beyond sound level—including, but not limited to, duration and acclimatization. The challenge, Davis said: to incorporate some of these additional sound characteristics—and the role of cumulative exposure to them—into current cumulative measures such as DNL that are all based around sound level.

Davies concluded her presentation with additional comments about sound quantification in the context of UAVs: It is important to listen to what people are saying about vehicle sounds; how people describe sounds should be considered alongside quantitative sound metrics; and hearing virtual vehicle designs has an important role in vehicle sound optimization.

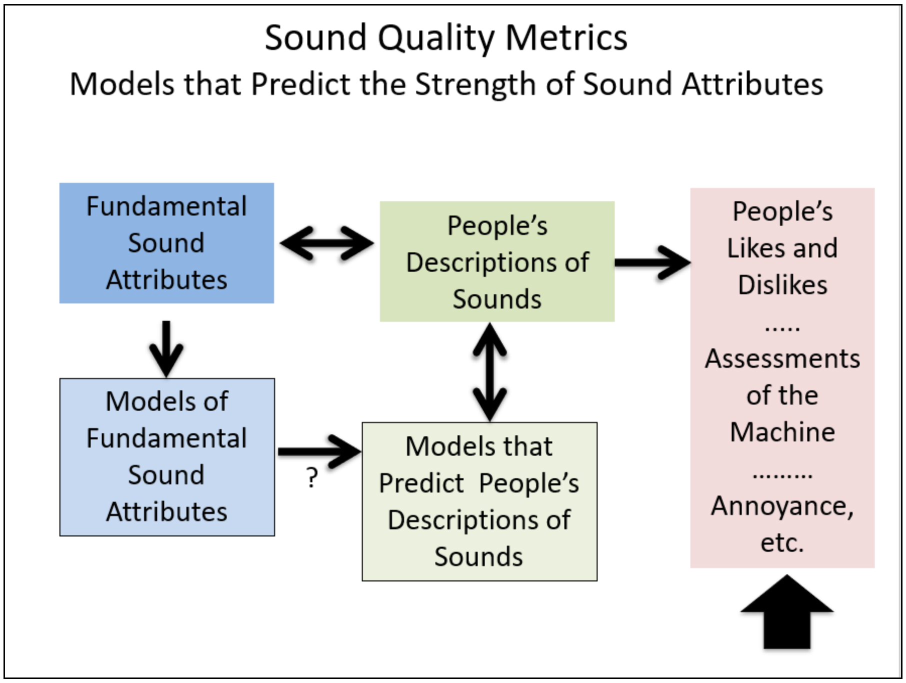

Figure 15-1 *Sound quality metrics: Models for predicting the strength of sound attributes*

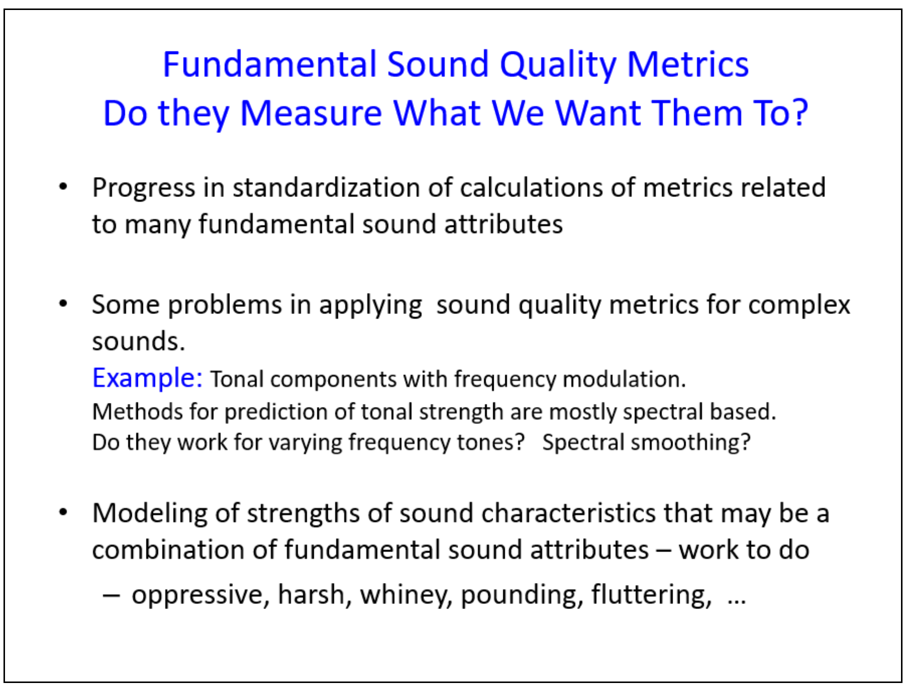

Figure 15-2 *Challenges of fundamental sound quality metrics with respect to UAVs*

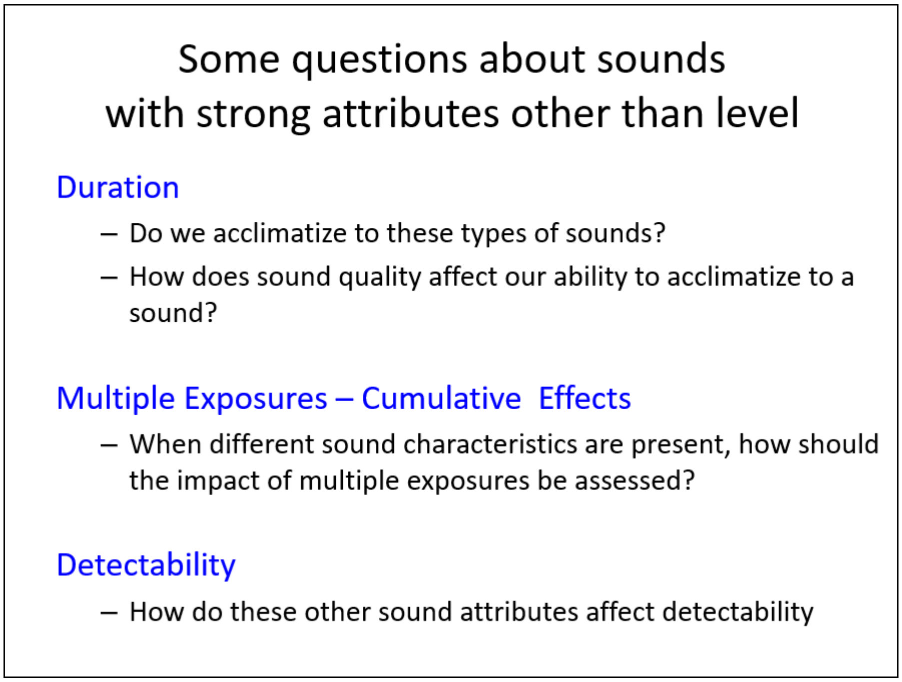

Figure 15-3 *Some questions about sounds with strong attributes other than sound level*

16. What Is a Sufficient Noise Metric?

Andrew Christian—NASA

The notion of a "sufficient" noise metric is relative and depends on a cost-benefit evaluation in a given situation, with the appropriate metric striking a balance between the power to resolve annoyance and the resources required for its use.

Andrew Christian, an aerospace technologist with the NASA Langley Research Center, addressed the question, "What is a sufficient noise metric?" Metrics run the gamut from very simple to very complicated, and some may be too complicated for a certain use. Christian's example: If a metric requires laboratory-quality data, it may not be appropriate for regulation.

The concept of a "sufficient" metric is a relative notion, not an absolute one. Metrics of various levels of detail will prove useful in different situations, based on the cost and benefit of using them. Simply put, and as summarized in Figure 16-1, the appropriate metric is the "parsimonious" one, restating the premise as, "It is foolish to do with more that which can be done with less." (William of Occam.) A tradeoff exists between a metric's simplicity and its power, the speaker pointed out, and a sufficient metric balances the power to resolve features of a noise germane to annoyance with the resources required to evaluate it.

Next, Christian more closely examined the meaning of "power" in this context. As summed up in Figure 16-2, power can refer to the ability to discriminate, in terms of annoyance, between vehicles in a class, classes of vehicles, or types of operations. Power comes at a price, he stated: Data or computational requirements must be considered, along with the fragilities or lack of robustness that tend to increase with escalating complexity.

Given that one could construe the issue of annoyance to be infinitely complex, Christian asked the rhetorical question, how is the appropriate tradeoff determined? This leads to the more interesting question: "What are the necessary conditions to have an increase in the complexity of regulations over time?" Before examining this question, Christian emphasized that he would be offering his own point of view, looking at the problem not from a single perspective such as a community noise researcher's or regulator's but considering the issue in terms of a single system that includes manufacturers, operators, and the affected community. With this frame of reference, one can draw parallels with other systems that have evolved complex regulatory mechanisms over time, noting that he would not be opining on what particular regulations or metrics are fitting for aerial mobility in particular.

There is a need for opposing forces within a bounded system. In the case of an airport, for example, the noise issue arises from people's opposing desires to live near the airport for convenience, but away from the noise that is annoying. Over time, the competing forces act to squeeze the system into a state of heightened complexity, to increase the "efficiency" of the use of the finite shared resource of space and quiet. In Figure 16-3, Christian spotlighted that, with a move toward a state of higher complexity, the cost of that complexity is overcome by the benefit of greater efficiency, which he demonstrated with two examples.

The presenter first discussed the tone-corrected perceived noise level (PNLT), which is considerably more complex than metrics based on A-frequency weighting. The PNLT metric was born in the mid-1950s, when Boeing wanted to begin using a modified Boeing 707 military jet for commercial passenger service but an anti-noise movement was taking root at larger U.S. airports. The Port Authority of New York/New Jersey retained Bolt Beranek and Newman (BBN) to conduct basic psychoacoustic testing to evaluate the noise from the 707 relative to propeller planes. Using the A-frequency weighting methods of the time, a 15 dB offset was identified between the two types of planes. To solve the problem, Karl Kryter came up with the PNLT metric via psychoacoustical testing, which was powerful enough to predict the response to noise from both aircraft classes without the need for a jet-mode "switch." The approach faithfully captured the human reaction to noise, based on nonlinear perceived noisiness with a correction for "tones" and a requirement of one-third octave band data versus time for the computation.

Although we now think of PNLT as being a somewhat rudimentary metric – as it is easily evaluated with a contemporary digital sound level meter – at the time the cost of computing (with analog equipment) it was incredibly high. Nevertheless, it was considered sufficient to bridge the gaps between the vested interests of the OEMs, operators, and the ensonified (and annoyed) population. Over time, PNLT became a worldwide standard for noise certifying commercial aircraft, which is still the case today. It has continued to serve its purpose well, and is now much faster to compute given the latest computer technology. This was an historical example of a complex issue with competing forces. The solution included increasing the complexity of the metric.

Christian next discussed a more recent example. In 2018 the drone company, Wing, carried out a trial of a drone-based package delivery service to suburban Canberra in Australia, including non-line-of-sight operations over homes. Initially, this was undertaken on a provisional trial basis with respect to noise, but noise was determined to be a major problem for those in the serviced community.

Among other things, Wing redesigned the vehicle, with an intelligent design with respect to noise that included a "lift-and-cruise" configuration, large propellers in front of lifting surfaces, and a lowered blade-passage rate for psychoacoustic improvement.
Operational mitigations were also put in place. With these adaptations, Wing was permitted to continue as a fully commercial operation in Canberra, with expansion to parts of Brisbane and to other countries. (NOTE: The summary by Blanks in this report covers a later Wing study in the United States where noise was not a major factor.—Ed.)

As of October 2020, Wing has made multiple thousands of deliveries, with only a handful of noise complaints. The Australian government released a position paper about "Emerging Aviation Technologies" and, with respect to noise regulation, proposed a construction for handling noise issues as they emerge but imposed no concrete limits.

In terms of whether this response met expectations, Christian examined the elements of the situation, as laid out in Figure 16-4: Wing operated only one vehicle, performed only one service, and operated over a very limited geographical and demographic area. And the company has been very judicious about their activities with respect to noise. The resulting regulation, then, is very parsimonious: No additional regulation resulted, with only a construction put in place in case of an arising need. The result is in keeping with his earlier analysis, with no need for increasing regulatory complexity over time given the circumstances.

Some may see a looming paradox, with the capital investment necessary to enable many of these UAM technologies seeming to be hindered by uncertainty in terms of noise regulation. But the regulations sought to decrease that uncertainty may only appear when a vested interest exists in increasing noise regulation commensurate with community reaction as highlighted in Figure 16-5.

In summary, Christian said the necessary conditions for regulations to increase in complexity over time may be both understandable and foreseeable. Still, he reiterated, this observation did not translate into any absolute position from him about what particular regulations or metrics will be sufficient for the UAS and UAM realm.

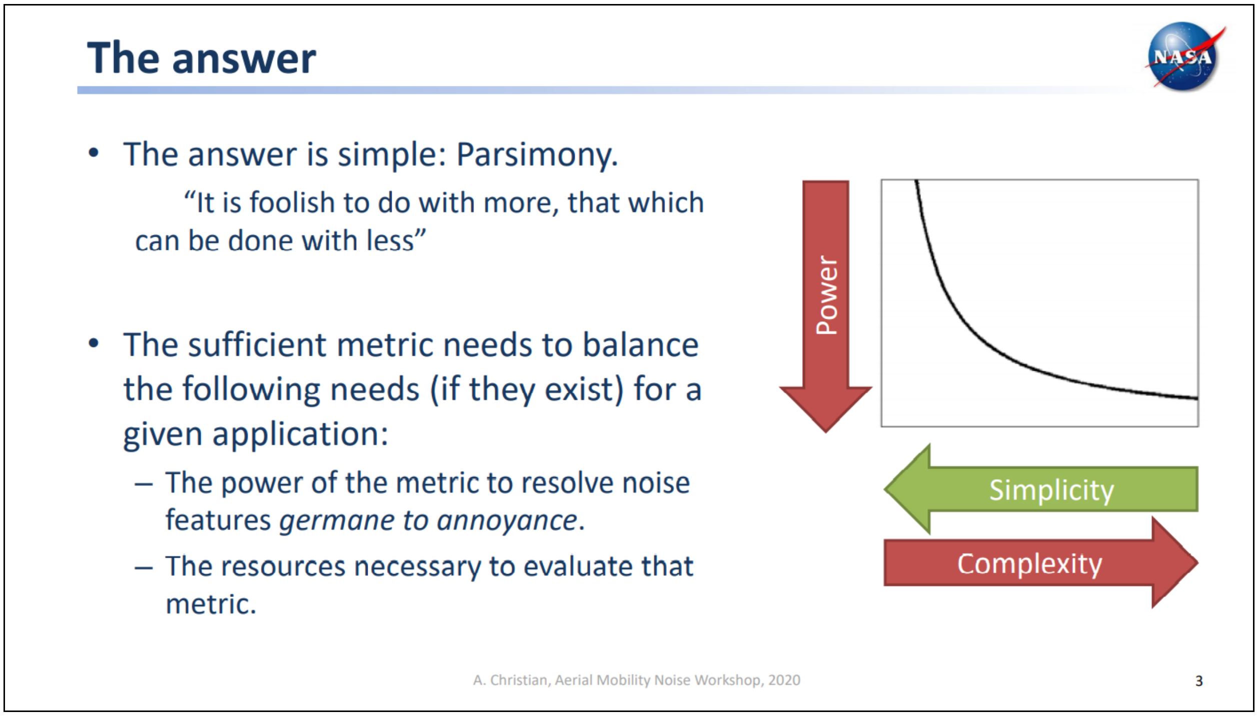

Figure 16-1 *Balancing a metric's power to resolve noise with resources needed*

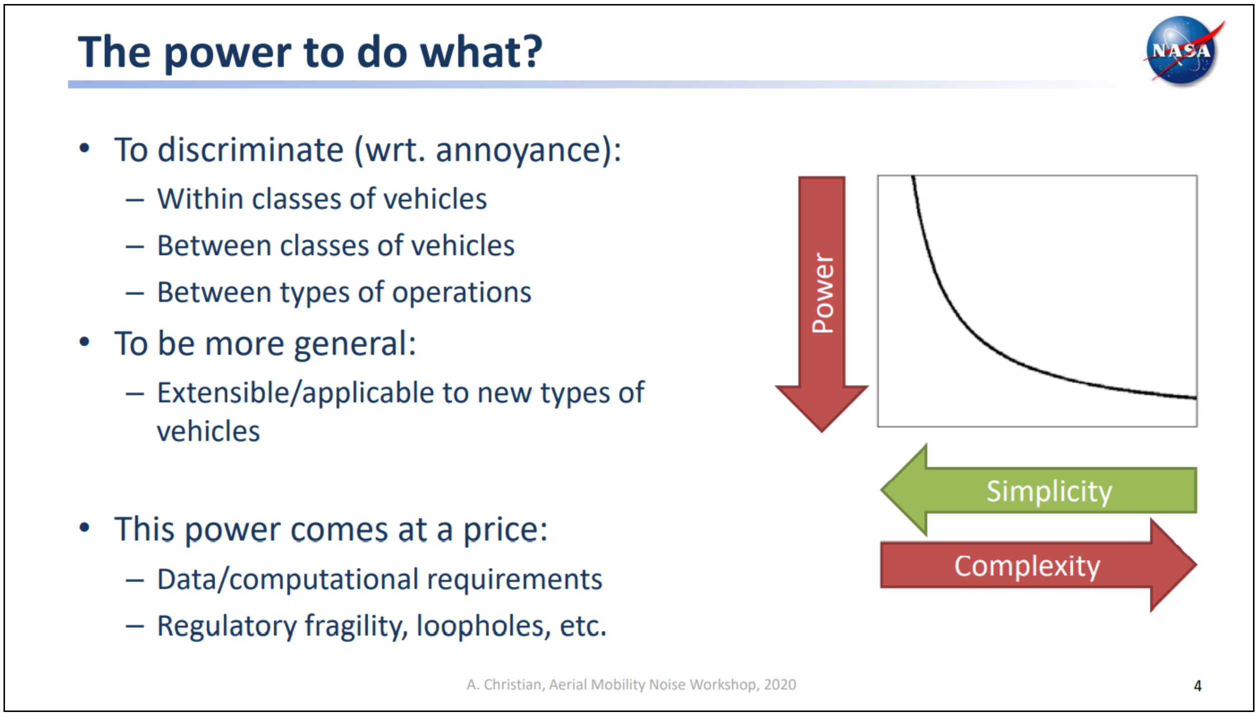

Figure 16-2 *Power to discriminate between sources of annoying noise*

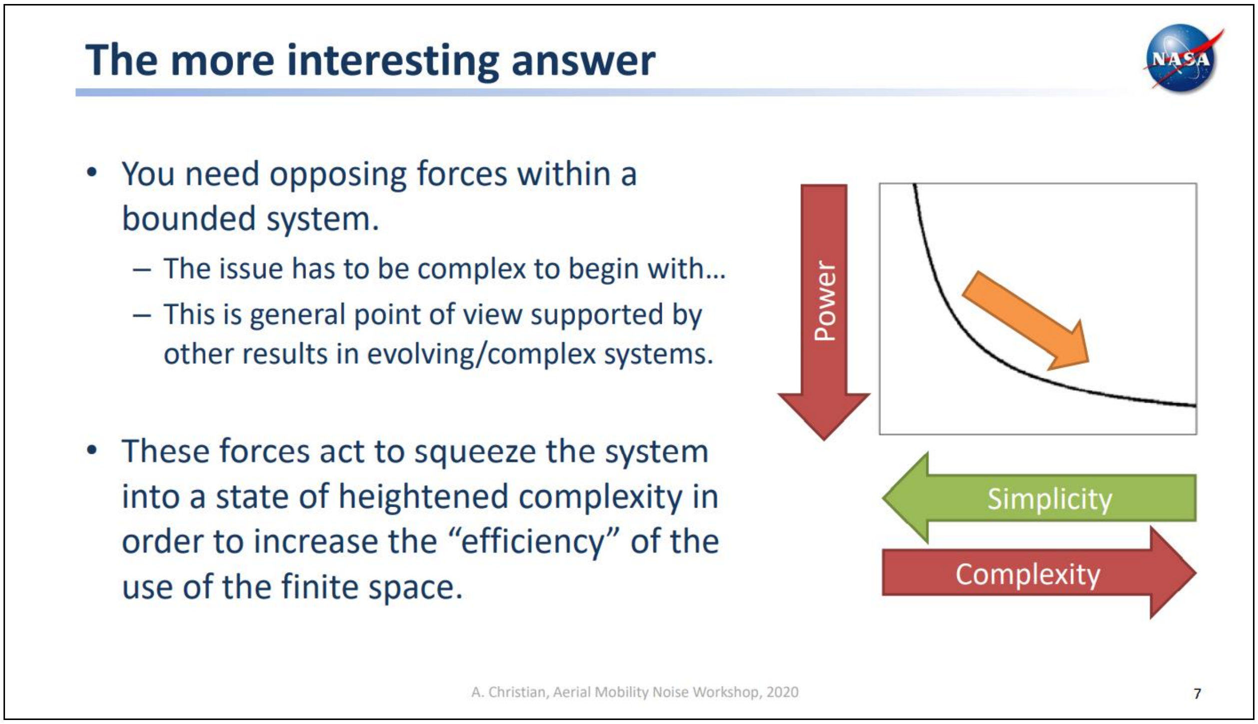

Figure 16-3 *Opposing forces achieve heightened complexity to increase efficiency*

Wing: What happened next?

- Does this square with our expectation?
  - Wing only operates one vehicle
  - It only performs one service
  - It does this over a very limited geographical/demographic area
  - The company has been judicious and proactive wrt. noise
  - The resulting regulation is very parsimonious: no additional regulation

→ This seems to make sense!

There are no elements in this situation that would lead us to expect increasing regulatory complexity over time.

Figure 16-4 *Wing example of regulation complexity consistent with need*

Where does this leave us?

Some may see this outcome as unfortunate, as it points to a looming paradox:

- The capital investment necessary to enable some of these advanced air mobility concepts is hindered by uncertainty regarding noise regulation.
- But the regulations sought to decrease that uncertainty may not appear until there is a vested interest to increase noise commensurate to the community reaction.

A. Christian, Aerial Mobility Noise Workshop, 2020 17

Figure 16-5 A looming paradox from the Wing experience in Australia

17. Air Mobility Operational Noise: Perception and Other Community Considerations

Judy Rochat—Cross-Spectrum Acoustics

Understanding is growing about the prospective community noise impact from aerial mobility vehicles. Spectrograms are helpful tools in visualizing the frequency content and other sound characteristics during aerial mobility operations. An understanding of people's perceptions—and how they translate into annoyance—is crucial for a fuller comprehension of what policies and mitigation measures, such as adjusting flight corridors, could be taken to fairly and effectively manage noise challenges from air mobility operations.

Judy Rochat, of Cross-Spectrum Acoustics, shared her expertise about elements of aerial mobility operational noise related to community impact, including perception and also spectral content, flight corridor considerations, and policy and enforcement factors. The speaker highlighted the contribution to presentation materials by her colleagues Herb Singleton and Keith Yoerg.

Focusing first on spectral content, Rochat explained that, by showing frequency content as a function of time, spectrograms provide a visualization of prominent tones and changes in spectral content during operations. Spectrograms processed with different bandwidths accentuate different tones, as reflected in Figure 17-1. Comparing the images from 1/3-octave to 1/12-octave to 1/24-octave bands, Rochat pointed out that prominent tones move from indistinguishable to progressively clearer. Figure 17-2, which the speaker displayed while playing audio of each of three vehicles shown, reflects the distinct sounds from each and the multiple prominent tones of all three.

Next, Rochat showed Figure 17-3, with the spectrogram comparison for aerial mobility and similar sounds (electric trimmer, circular saw, and bees). And in the Figure 17-4 "slice-in-time" spectrogram of a research quadcopter, Rochat spotlighted the appearance of four harmonically related sets of peak frequencies, assumed to be related to the four propellers. Among the observations she underscored: The aerial mobility noise has both harmonically related and inharmonically related peaks, with the latter seeming to result from the different propellers.

The speaker's next area of focus was the significance of frequency relationships in terms of human perception. A direct relationship exists between urgency and annoyance, and the relationship is affected by the context of how appropriate the urgency seems. As the fundamental frequency increases, the sound is perceived as being increasingly urgent, with a fundamental frequency between 1,000 and 2,500 Hertz seeming most urgent.

Rochat explained that the existence of three or more harmonics makes a sound more alarming or urgent, and contributes to the sound's harshness. Also, a random series of harmonics is perceived as most urgent, contrasted with regular series or integer multiples, which are perceived as least urgent. Minimizing the combined noise from all the different propellers and the resulting inharmonic relationships could decrease urgency or annoyance, she stated. The speaker offered this unanswered question for attendees' consideration: Does the perception of a threat—such as an overhead object striking the listener—factor into noise annoyance? Rochat also mentioned dissonance—the combination of frequencies that may sound jarring, unpleasant, or threatening—and that inharmonic fractional relationships are present with a phase relationship that is not stable.

CSA

The next area the speaker took up was flight corridors. In the context of highway and rail transportation noise sources and how those and air mobility noise sources affect each other, Rochat shared these ideas, among others:

- Air mobility noise might be more noticeable in locations along highway corridors where noise barriers have been installed.
- Environmental justice should be considered. Operating aerial mobility vehicles in communities where people are already exposed to higher levels of noise from highways and rail lines would compound noise issues for people in these areas.
- Alternating aerial mobility vehicle routes—for neighborhood package delivery, for example—can minimize noise annoyance resulting from the same people being continually exposed to noise.
- Noise and annoyance can be managed by selecting a route with features, natural or man-made, that help shield noise.
- Especially where buildings and other features are *not* shielding noise, flying a vehicle at higher altitudes until descent can also reduce noise.

In concluding her presentation, Rochat spoke briefly about policy and enforcement considerations, raising the yet-to-be-answered question of whether local noise ordinances will apply to aerial mobility deliveries. Some local ordinances apply to truck deliveries, the presenter pointed out, which consider these deliveries to be an area noise source rather than a transportation noise source. And some existing ordinances have time-of-day limits and/or maximum sound pressure restrictions tied to the time of day or night.

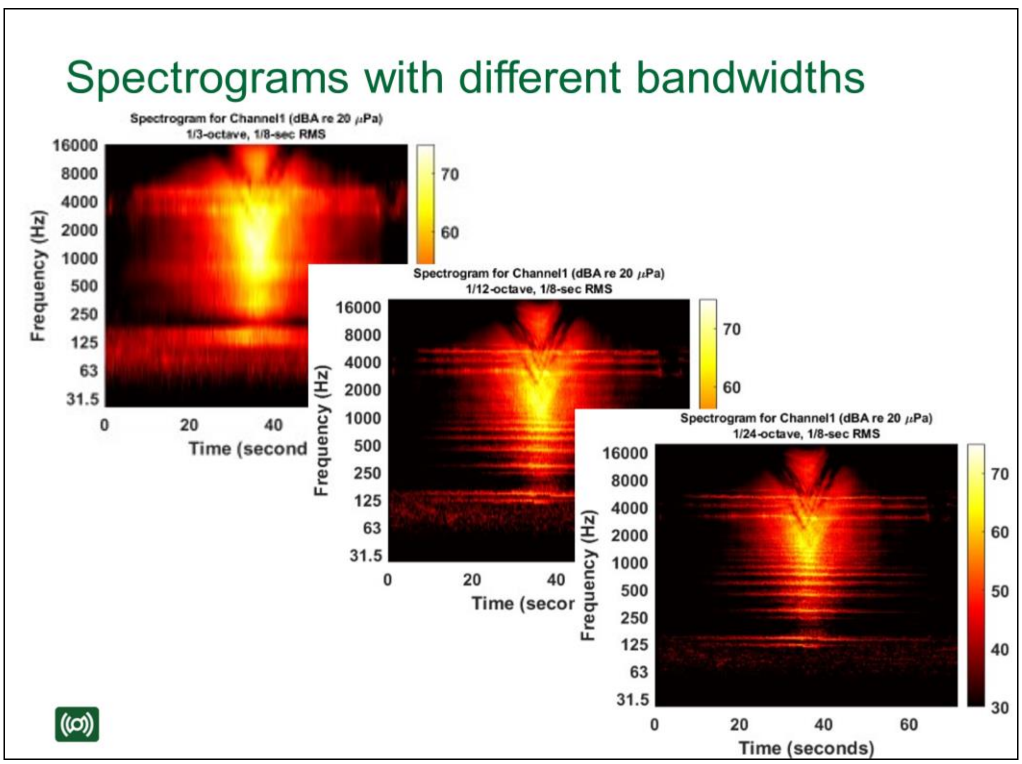

Figure 17-1 *Spectrograms vary as bandwidths change*

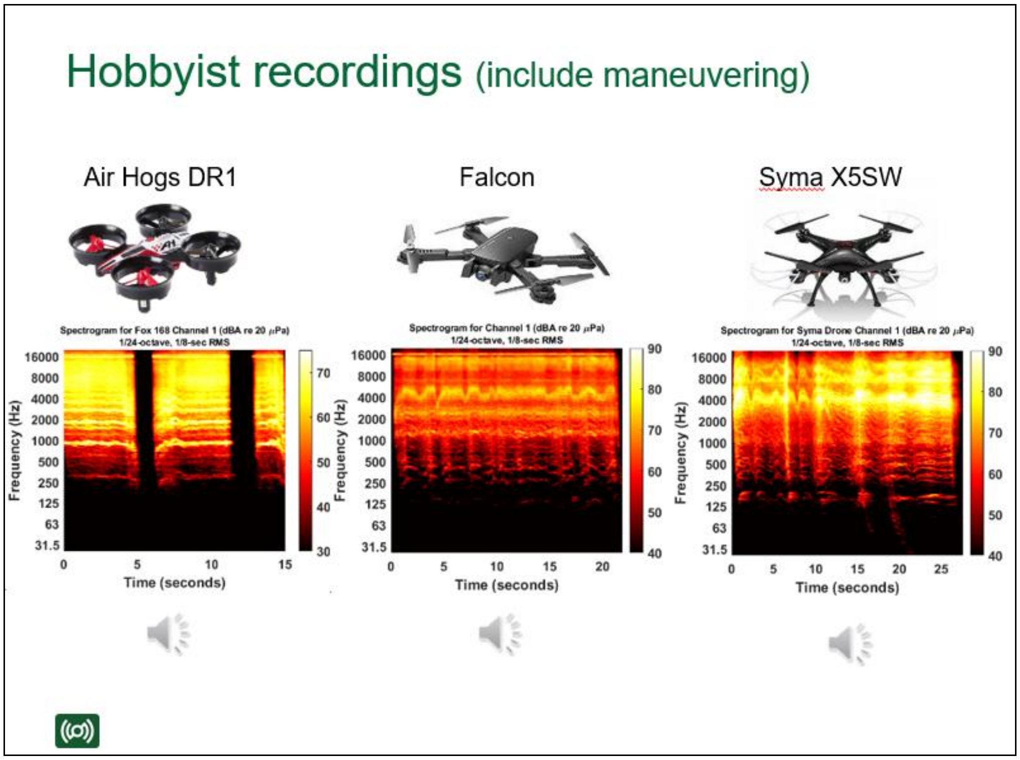

Figure 17-2 *Hobby vehicle spectrograms*

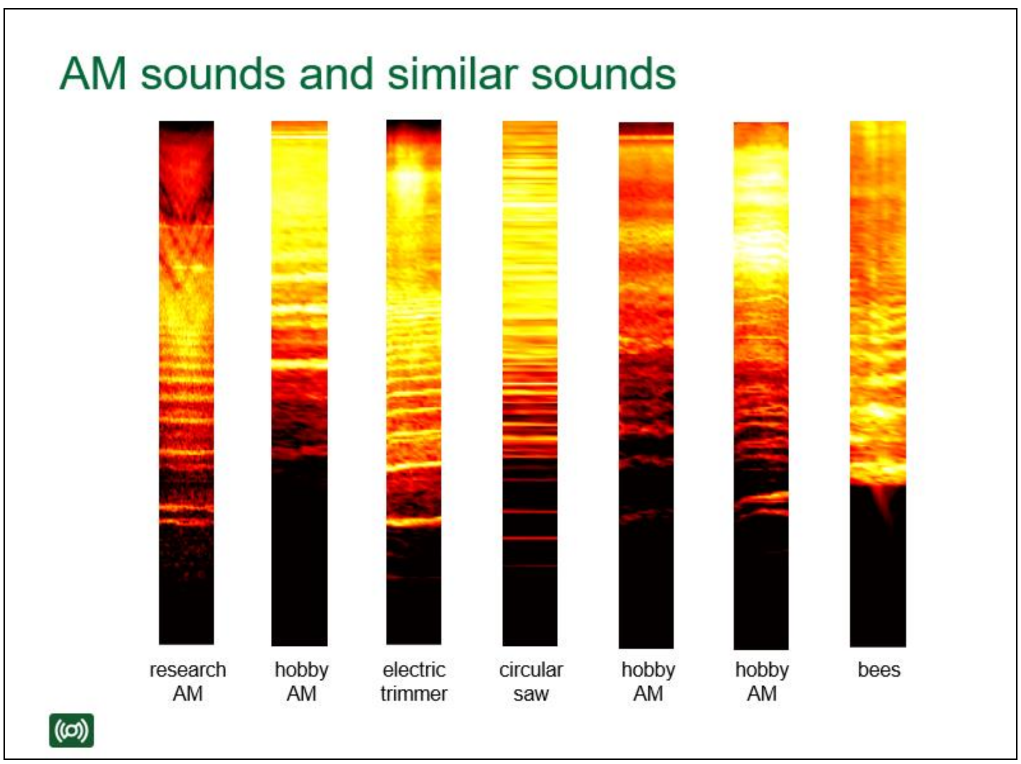

Figure 17-3 *Aerial mobility (AM) and other sounds on spectrogram*

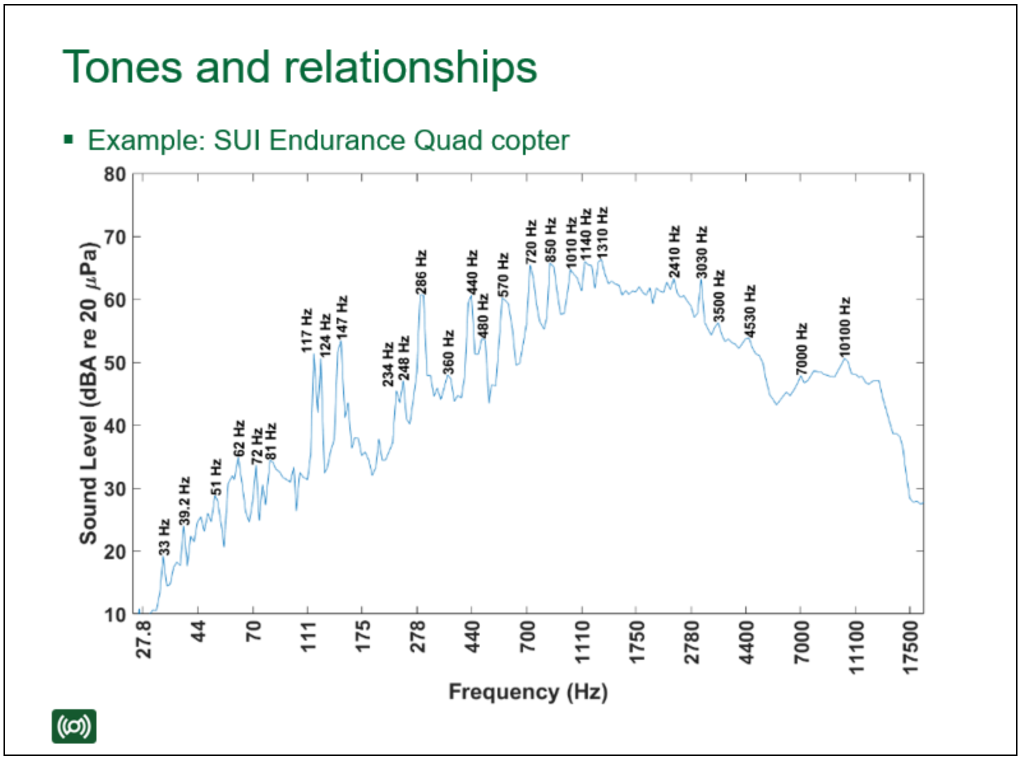

Figure 17-4 *Quadcopter spectrogram: tones and relationships*

18. Reducing Community Noise from Delivery Drones Through Route Optimization

Eddie Duncan and Kenneth Kaliski—RSG Inc.

A novel case study has looked at the potential for route optimization to reduce the noise from delivery drones. In this study, the research team examined drone routing's promise for reducing annoyance by identifying areas where less people would be exposed to the noise and where masking would offer the greatest prospects for reducing sound perception.

On behalf of himself and RSG senior director Kenneth Kaliski, Eddie Duncan, a director in RSG's acoustics practice, discussed a community noise case study conducted by his company. The case study focused on reducing potential noise impacts from commercial drone delivery services through noise mapping and route optimization. It was set in Chittenden County, Vermont, which is rare for having a regional noise map. The speaker emphasized the hypothetical nature of the case study, and that the research team was not aware of any proposed delivery services for the area studied.

The premise of this work was that noise can be annoying, which requires it to be "at least audible and, more likely, noticeable." Annoyance can be lessened by reducing audibility through sound masking using existing noise or by minimizing population impact. The study explored the use of sound propagation modeling, with existing community noise maps and background sound level data, to assess a variety of flight route options and short-term maneuvers in the context of residential package delivery.

The community noise map, coupled with historical sound level measurements in the area, provided a baseline for the study. In modeling the UAV sound, the team sampled 50 residential delivery locations, categorized as busy roadway areas, suburban areas, or rural residential areas. The study used a general range of background sound levels associated with each of these categories. A drone depot location was selected based on proximity to a highway network for receiving a supply of goods and a location in an industrial area within a reasonable distance to residential communities. In terms of sound emission data, the team used data from a commercial-grade hexacopter (DJI Matrice 600 Pro), from Virginia Tech's Nathan Alexander [8]. Sound emission data on commercial-grade drones is sparse, Duncan noted, expressing the hope that such data would become increasingly available.

RSG's case study considered four routing options: direct between the depot and each delivery location; via the most direct roadway paths from depot to delivery location; via a low-population waterway corridor over Lake Champlain, with spurs to each delivery location; and using another low-population corridor, along a railway, with spurs to each delivery location.

Flight routes are depicted in Figure 18-1. The model used a vertical takeoff from the depot to a height of 41 meters, travel along a flight path at 70 miles per hour, and hover at 7 meters to each delivery point. These flight and hover elevations and speeds are comparable to some commercial delivery service pilot programs, the presenter stated. While the analysis was limited to 50 delivery locations, it looked at projected sound levels at 26,000 residences in the hypothetical delivery area.

[8] Alexander, W. N. and Whelchel, J. "Flyover Noise of Multi-Rotor sUAS." Inter-Noise 2019. June 2019

The presenter next discussed result highlights. Figure 18-2 shows UAV overflight sound level at receptors with varying horizontal distances from the flight path. For a receptor directly under the flight path (in red), the maximum sound level was approximately 52 dBA, which falls within the background range of a busy roadway area and above the background levels for a suburban neighborhood or rural residential area. At 50 meters from the flight path (in purple), sound levels are about 48 dBA—below the lower end of the busy roadway background range, but still above ranges in many suburban and rural residential areas in Chittenden County. It takes a setback distance of 150 meters (in orange) to see sound levels reduced to 40 dBA—a level at the lower end of suburban neighborhood background sound levels and at the high end for rural residential areas. Finally, a 325-meter setback distance (in blue) reduces sound level to around 33 dBA, just below the low end for a rural residential area of the county.

Hovering for delivery results in the highest sound levels at a residence due to the receptor's proximity to the drone, Duncan said, noting that this hovering is short in duration. Figure 18-3 reflects a sample residential neighborhood from the case study, where daytime background sound ranges from 38 to 48 decibels; A-weighted sound levels from the UAV at the delivery point are 60 to 70 decibels during hover; and resulting sound level for nearby neighbors is about 55 decibels.

The presenter next noted that his presentation had so far focused on overall sound levels, while annoyance stems largely from audible tones, along with various psychoacoustical parameters. Given that audibility usually precedes annoyance, masking UAV noise for some portion of the time may reduce negative community reaction.

Ideally his research team would be able to conduct a narrowband analysis of masking and tonality for this study demonstrating methods, but the lack of sufficient narrowband data from a representative delivery drone led to the use instead of a simplified analysis using one-third octave bands. As reflected in the graph in Figure 18-4, the sound pressure level of the drone passby is largely masked by the busy road background noise (except in frequencies above 2 kHz), with less masking seen in the suburban example and even less in the rural areas. The presenter stated, "We think this indicates there may be some opportunities near busy roadways to mask some of the sound from UAVs, less so in quieter environments."

As captured in Figure 18-5, the research team also considered the four flight routes—direct, roadway, waterway, and railway—in terms of the noise exposure to the population overall. Looking at a one-hour-equivalent sound level from 50 drone deliveries (including takeoff, flight path travel, and hover at the delivery location), waterway routes provided the least exposure, and direct and roadway routes provided comparable exposure, higher than the waterway paths. Railway routes resulted in the highest exposure due to their proximity to residences—initially surprising, and explained by the number of homes revealed to be situated near the rail line in a portion of the case study area.

Regional- and community-scale noise maps have a potential role in planning for new noise sources such as drone delivery vehicles, Duncan said. The map in Figure 18-6 shows the sound level from 50 would-be drone deliveries over the course of about an hour, overlaid on the ambient daytime sound level from the Chittenden County noise map. With better mapping of existing ambient sound levels, coupled with additional GIS data, drone routing could be optimized to reduce the likelihood of annoyance by identifying where people are less likely to hear sound and where sound could be well masked. This approach might also help in identifying areas where operators would be more likely to receive complaints.

For route optimization via noise mapping to be most effective, traditional large-scale noise mapping may have to evolve to show spectral content within specific frequency ranges and potential variations by time of day or day of the week. "A good place to start is by increasing noise mapping of urban and suburban areas," said Duncan. "This noise mapping could be a valuable tool for regional land use planning conversations, whether involving potential drone operations or not."

Summing up the findings from the RSG case study, the presenter highlighted that noise mapping, coupled with an analysis of routing options, was shown to represent a powerful tool for quantifying and reducing noise impacts from drone delivery services. To take advantage of the potential for routes over certain areas to provide a level of masking and reduce noise impacts, more and better information is needed on drone sound emissions, however. He added that masking may only represent a practical tool in busier areas, pending quieter drone technologies, with hybrid routes that focus on uninhabited working landscapes and areas that provide some masking appearing to have the least impact.

In concluding his presentation, Duncan highlighted a concern that drone routing presents potential equity and justice concerns. If drones are to be routed over noisier areas to mask the sound and reduce impacts, it must be recognized that disadvantaged populations commonly live in these noisier areas that could be subject to yet more noise from drone deliveries.

Duncan and his colleague Kenneth Kaliski answered some questions from attendees related to the presentation topic.

- *Question: Have you looked at total flight times and distances based on different routing techniques?*
  Answer: We plan to examine this question as the case study continues. Recognizing that some flight routes among these spurs off the main corridor result in significantly longer flights, a hybrid approach might use the corridor while attempting to minimize flight distance.
- *Question: On a related note, did you consider that a vehicle's turns often require a slow-down, and in turn a longer flight time and more exposure compared to a straight-line flight?*
  Answer: We took this into account to some extent by including the direct route in our comparisons to capture the straight path. Other options look at using a primary corridor, with only one turn-off to a delivery location. A delicate balance exists between using a corridor and trying to reduce flight time.
- *Question: Did you consider environmental justice in this case study?*
  No. Although the issue is on our radar and we want to address this as a next step, we did not look at the specific population in this context.
- *Question: Which software package was used for the noise modeling?*
  We used CadnaA for both aerial and ground sources.
- *Question: What is the basis for using L50 ambient noise level as the reference?*
  We provided a range of data—L90, L50, and LEQ—with L50 considered to be a reasonable approximation of median sound level.
- *Question: What consideration was given in terms of number of operations?*
  We chose the sample of 50, recognizing that predicting the growth of delivery services in a given area represents an outstanding challenge.

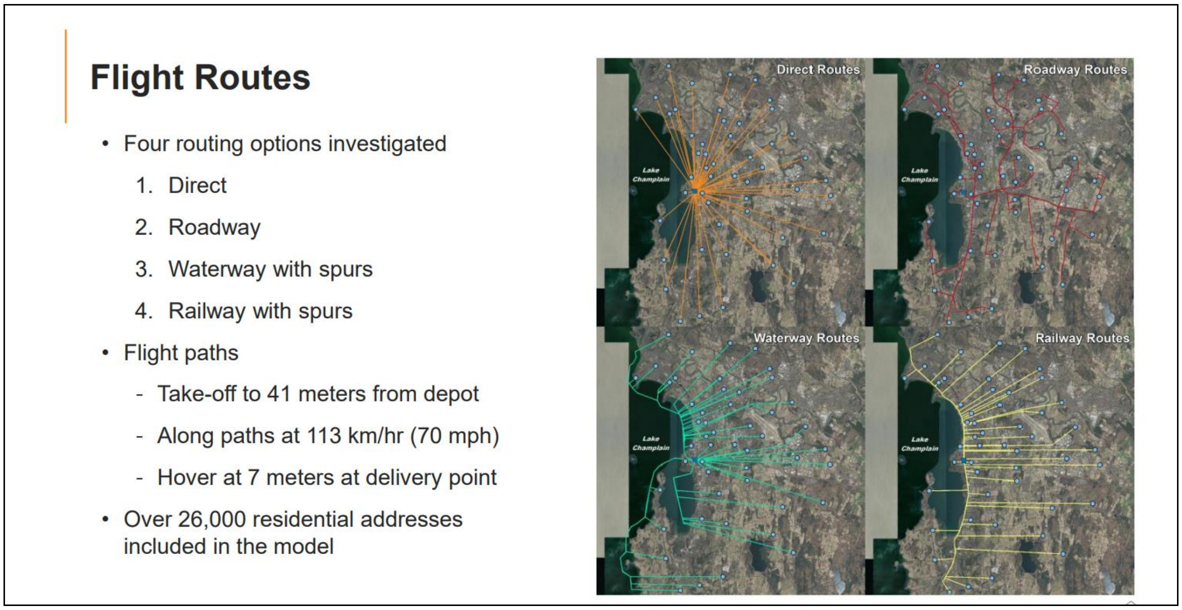

Figure 18-1 *Flight route options investigated*

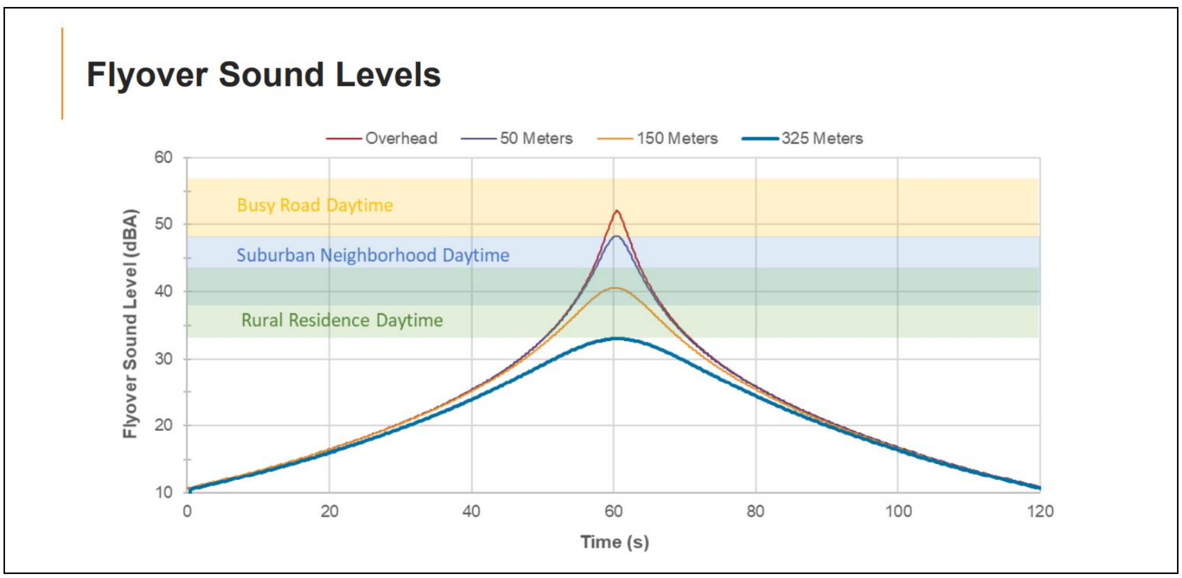

Figure 18-2 *UAV flyover sound levels*

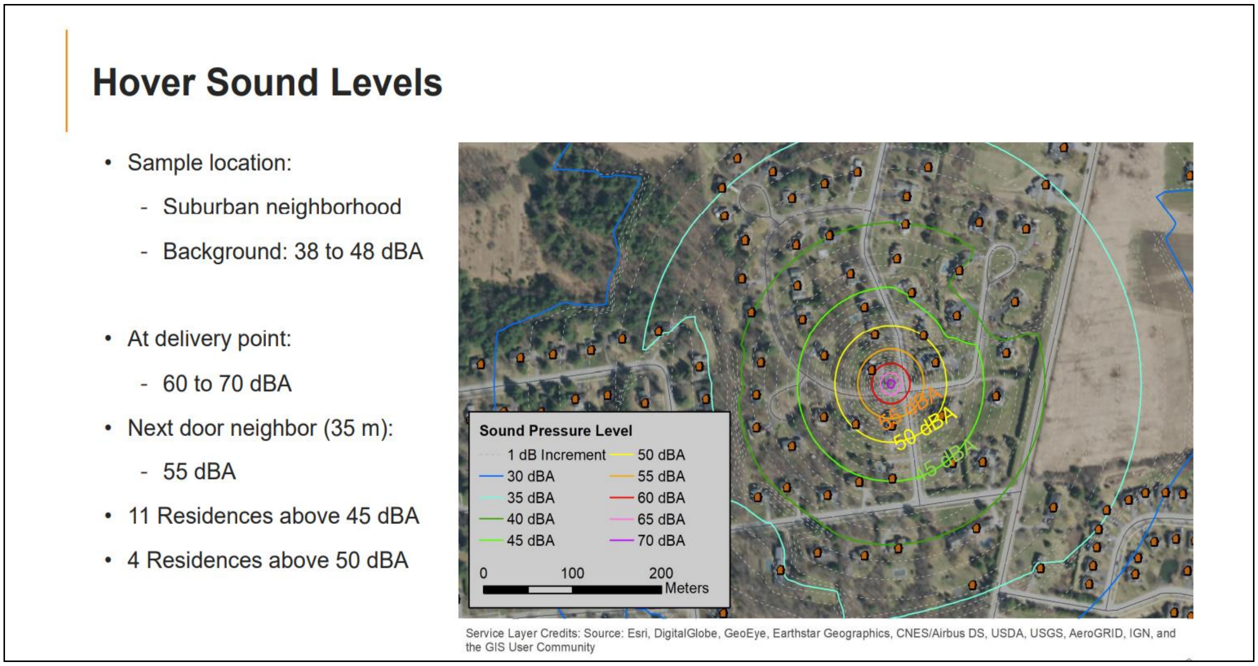

Figure 18-3 *Hover sound levels in a suburban neighborhood*

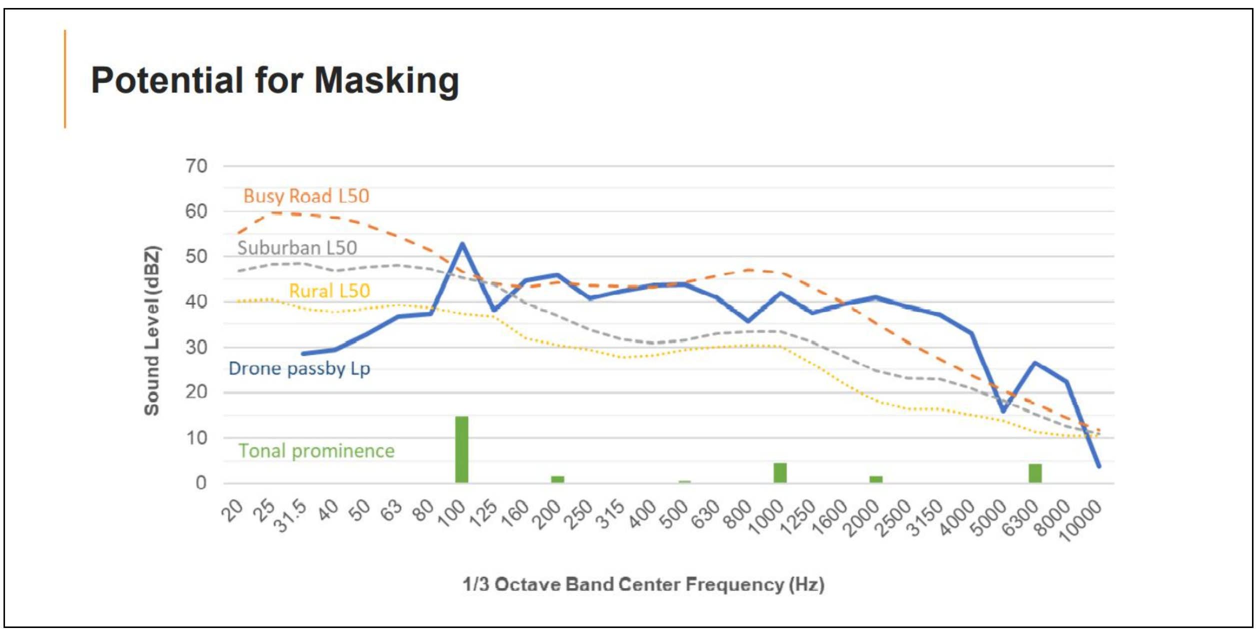

Figure 18-4 *Potential for masking: busy road, suburban, rural*

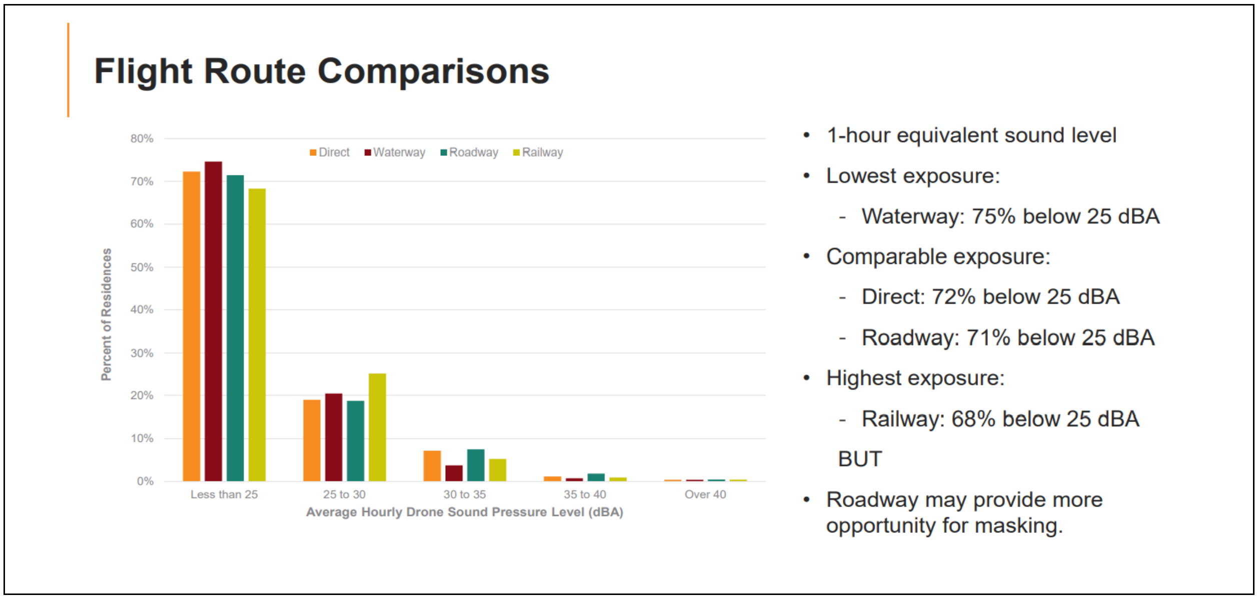

Figure 18-5 *Population noise exposure by flight route*

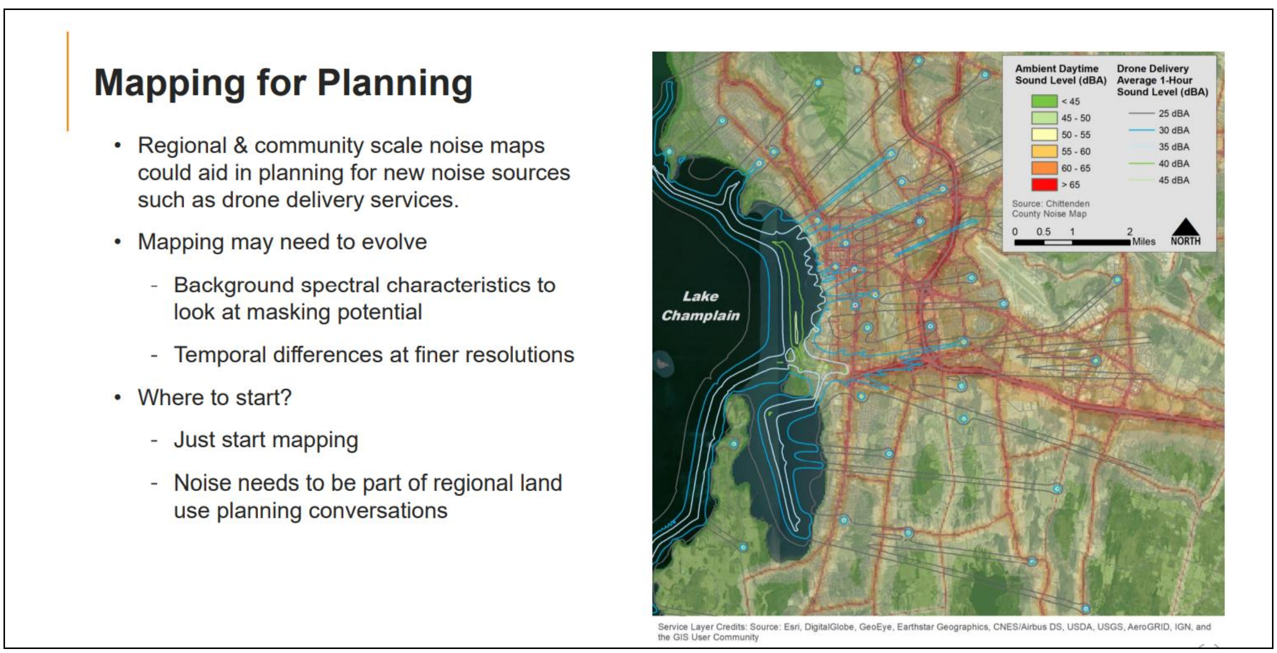

Figure 18-6 *Evidence for planning: ambient daytime sound levels over an hour of delivery by drone*

19. Community Response to UAS Noise in the Virginia IPP

Mark Blanks—Virginia Tech Mid-Atlantic Aviation Partnership

Effective outreach is critical for gaining community acceptance of UAS—whether the context is a small package delivery operation or broad UAM integration. Where UAS noise is concerned, mitigation steps can include thoughtful consideration to operation hub locations, flight path decisions, and efficient aircraft design. Still, affected people on the ground must also understand a service's value to their community and be assured that their concerns are taken seriously.

Mark Blanks spoke at the aerial mobility workshop from his perspective as Director of the Virginia Tech Mid-Atlantic Aviation Partnership, an FAA-designated test site and the UAS Integration Pilot Program (IPP) site for Virginia. (The IPP has since evolved into the FAA's BEYOND program.) Blanks discussed the drone package delivery project, undertaken in collaboration with drone company Wing, that was one of the Virginia IPP site's three projects as presented in Figure 19-1. In particular, he focused on the extensive community engagement by the IPP team with the residents of Christiansburg, Virginia, the town near Virginia Tech where the project's package deliveries took place.

Early in the project extensive testing was conducted—including deliveries to two actual residences, as depicted in Figure 19-2—in pursuit of an air carrier certificate from the FAA. The IPP work earned Wing the UAS air carrier certification from the FAA, which was the first ever awarded, in April 2019. This "landmark achievement" led to the launch, in October of the same year, of the first residential commercial drone delivery service in the United States. "That was a historic moment," Blanks said, "seeing this system actually up and running in Christiansburg, delivering packages to people's yards and driveways." The presenter noted that the COVID-19 pandemic, which confined people to their homes and drove a desire for contact-free delivery, led to a five-fold hike in demand for the drone deliveries.

Bringing new drone technologies right to local homes requires direct interaction with customers. This calls for a whole new level of interaction and acceptance compared to the interaction with aviation that used to happen only at the airport. Blanks: "At the end of the day, the service has to be valuable to customers and acceptable to the broader community."

In the case of the IPP package delivery project, community acceptance grew from extensive engagement efforts, which are summarized in Figure 19-3. In October 2019, even before launching operations, the IPP team embarked on an extensive outreach effort, recognizing that a lack of information can drive a community's fear. The team reached out early to stakeholders including local elected officials, first responders, and other leaders, and also to those in the aviation community such as helicopter EMS operators and airport managers.

Then the group expanded engagement to the general public at local gathering places such as malls and regional festivals. "We wanted to educate the public to help them understand what the technology was, why it was there, and what it was doing to bring value to the community," Blanks said. And importantly the team wanted to listen to the residents: What were their concerns, and what would they want to see in a drone delivery service? After educating and listening to residents, the group responded to their concerns, addressing issues where possible and at least undertaking meaningful dialogue to assure residents they were being heard.

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Community reaction to the drone delivery service was overwhelmingly positive, breaking down as 86 percent positive, 13 percent neutral, and 1 percent negative. The "success story" is in the continued positive sentiment from the community. With ongoing community engagement, residents remained very positive about the drone deliveries more than a year after the operations began.

The concerns about package delivery by drones fell into the category of noise and two others: safety and privacy. In terms of safety, air carrier certification and testing work provided assuring data points. As for privacy, this is less of a concern in this delivery context than it would be when a camera is examining a situation on the ground which raises concerns about "spying." Blanks explained that common worries about noise from drone deliveries included interference with a private occasion and the potential impact on birds.

Based on its drone delivery experience in Australia, Wing took three major actions to manage noise from its operations:

- *Locating its "nest," or operations hub for takeoffs and landings, away from residential areas.* The nest was in a commercial district of Christiansburg, far from the nearest home.
- *Randomizing flight paths, with the aim of approaching from a different angle for repeated deliveries to the same place.* This is contrary to the "corridors" approach used today at many airports, which presents an extreme nuisance to a small segment of the population living under concentrated flight paths. By reducing the noise experienced by any one person, reception was greatly improved. In response to a workshop attendee's question, Blanks specified that randomized flight paths are determined by Wing's sophisticated software algorithm. He also noted that Wing has been very involved in addressing barriers to UAM integration by contributing its path planning expertise and technologies to UAS traffic management efforts.
- *Designing aircraft with noise reduction in mind.* Wing took the proactive steps of adjusting propeller designs and aircraft configurations to reduce noise. "Now we have a design that is less noisy than a car driving down the road, and far less noisy than a package delivery truck coming up the driveway" Blanks said.

While recognizing differences in factors such as scale, size, and noise, all things considered, the community acceptance observed in the Virginia IPP project bodes well for the urban air mobility operations of the future. Blanks summed up that gaining the needed acceptance for UAS and UAM relies on maximizing the value to communities, while ensuring that their concerns are addressed. Blanks expressed the belief that UAM integration can be achieved even without time, place, and manner restrictions—in true partnership with affected communities.

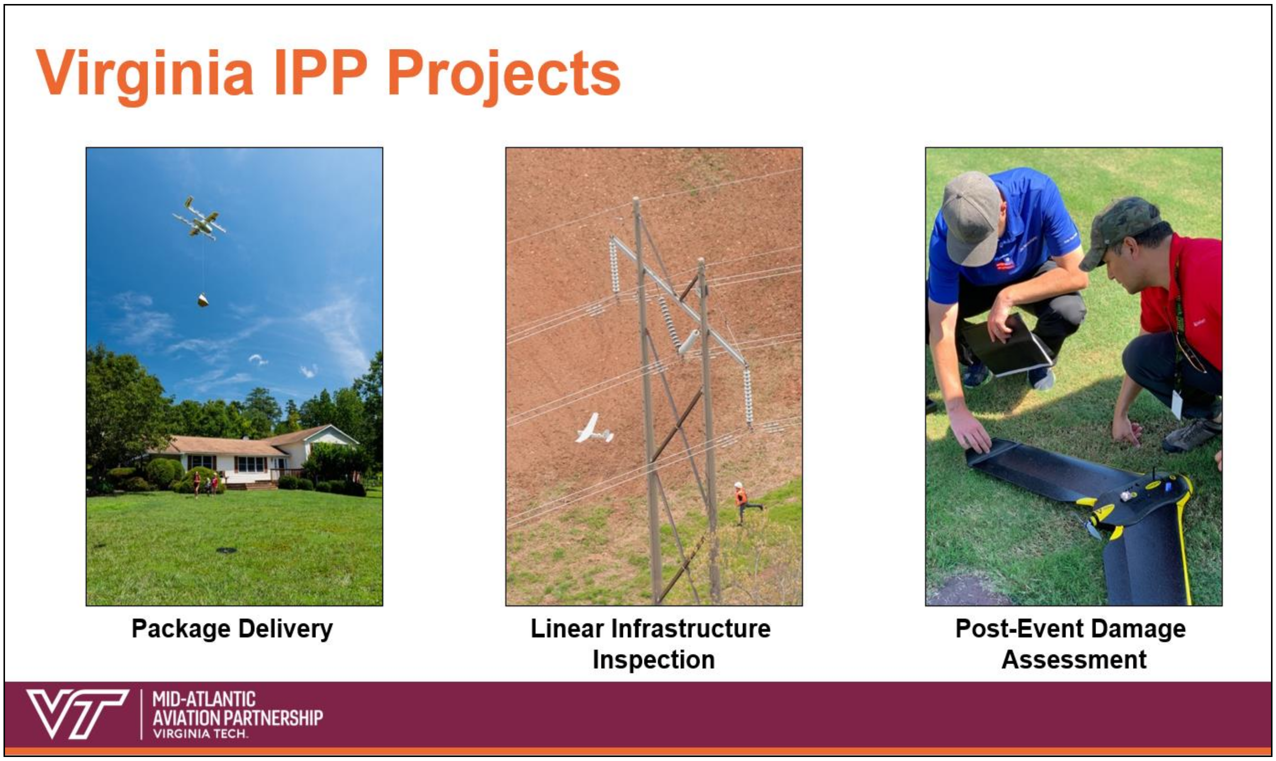


Figure 19-1 *Drone package delivery is one of three Virginia IPP drone projects*

Figure 19-2 *IPP testing led to the first FAA UAS air carrier certification*

Figure 19-3 *Community engagement was important*

20. Advanced Air Mobility: Facilitating Community Acceptance

Mary Ellen Eagan—HMMH

Advanced air mobility raises unique noise and annoyance concerns, and tailored communication strategies are recommended to win buy-in from diverse stakeholders and support successful incorporation of AAM vehicles into the national airspace. The conduct of specialized research and development of customized metrics could likewise advance the U.S. toward smooth AAM integration.

Mary Ellen Eagan, president of HMMH, focused her presentation on recommendations for addressing community concerns about advanced air mobility noise based on HMMH experience with community reaction to aircraft noise, and in particular on the importance of effective communication strategies tailored for a range of stakeholders. In addition, she spoke about noise metrics and noise modeling for regulatory review. Eagan explained she would use the term "advanced air mobility" (AAM), which FAA and NASA are using as an expansion of the term "*urban* air mobility" to encompass operations not specific to urban environments, including commercial inter-city operations, public services, and recreational air mobility vehicles.

Many groups are crucial to the successful integration of advanced air mobility into the national airspace, including AAM original equipment manufacturers, AAM operators, airport operators, FAA officials, local governments, and the general public. Effective communication with each group is essential to this success; while conveying consistent broad themes, messages should be tailored in specific content and format in recognition of varying roles, needs, and interests. Figure 20-1 contains some recommendations for gaining public acceptance, and Figure 20-2 provides additional suggestions regarding reaching out to diverse audiences.

Acceptance of AAM requires management of visual, privacy, and noise concerns. And AAM-associated services raise their own concerns: For example, customers' use of public transit, private vehicles, rideshare services, and other means to reach vertiport access points raises a secondary annoyance factor. In addressing these various issues, avoiding broad meetings in favor of more narrowly targeted communication opportunities is recommended, as acceptance of decisions and outcomes improves when people feel decision-makers have heard and understood their concerns. Effective engagement strategies must be ongoing and evolving to address concerns over an operator's entire tenure and not just at the outset.

In the speaker's view for the FAA's part, community engagement relating to AAM should be proactive, as communication ahead of implementation can enhance community buy-in. Engaging city officials is also important to community acceptance by conveying the benefits of AAM operations for these representatives and their neighbors.

The FAA has authority over AAM vehicle certification; integration into, and separation from, the national airspace system; and evaluation of operational and environmental effects. AAM proponents should provide data and research needed to help the agency respond to stakeholders' concerns and move policy from concept to reality. This research falls into three key areas: annoyance research to address challenges with community acceptance, vehicle certification-related research, and modeling to meet regulatory requirements.

Eagan discussed the noise and annoyance metrics used to measure and quantify noise effects on the community. The FAA relies on effective perceived noise level (EPNL) for the certification of aircraft and requires the use of day-night average sound level (DNL) for airport and aviation noise exposure studies. But recent research suggests that current metrics may fall short of capturing the full spectrum of AAM concerns. This raises the significant challenge of identifying noise metrics that better correlate with noise and annoyance from AAM, and gaining FAA acceptance by demonstrating these metrics' usefulness, relevance, and accuracy.

Conducting and funding research on annoyance from AAM is imperative, Eagan stated, highlighting that current research focuses on annoyance based on operations for traditional aircraft, while AAM aligns more closely with general aviation and helicopter operations. AAM's operational concept will result in more intimate interaction with surrounding communities. Also, the on-demand and last-mile nature of AAM may result in flights at inconsistent hours, altitudes, and flight paths—patterns that starkly contrast with those the general public has come to expect from air travel.

These differences will likely change the community's threshold for annoyance, and her company recommends that academic institutions, original equipment manufacturers, operators, and other AAM stakeholders identify and conduct research addressing the effects of potential AAM concepts on operation, and specifically on annoyance and associated dose-response curves.

Eagan spoke briefly about AAM noise issues in the context of the National Environmental Policy Act (NEPA). She discussed FAA Order 1050.1F, "Environmental Impacts, Policies, and Procedures," as well as the Aviation Environmental Design Tool (AEDT) and the modeling adjustments necessary for modeling applicable to AAM vehicles.

The speaker concluded her presentation by reiterating the importance of community acceptance to the success of advanced air mobility, and to that end, the importance of adopting tailored and comprehensive community engagement strategies to foster that acceptance. Stakeholders must address standards, certification, and the integration of AAM into existing infrastructure. Across these areas, additional research is needed, and specialized metrics may be required, to adequately describe and address the unique noise, annoyance, and other concerns arising in the AAM context.

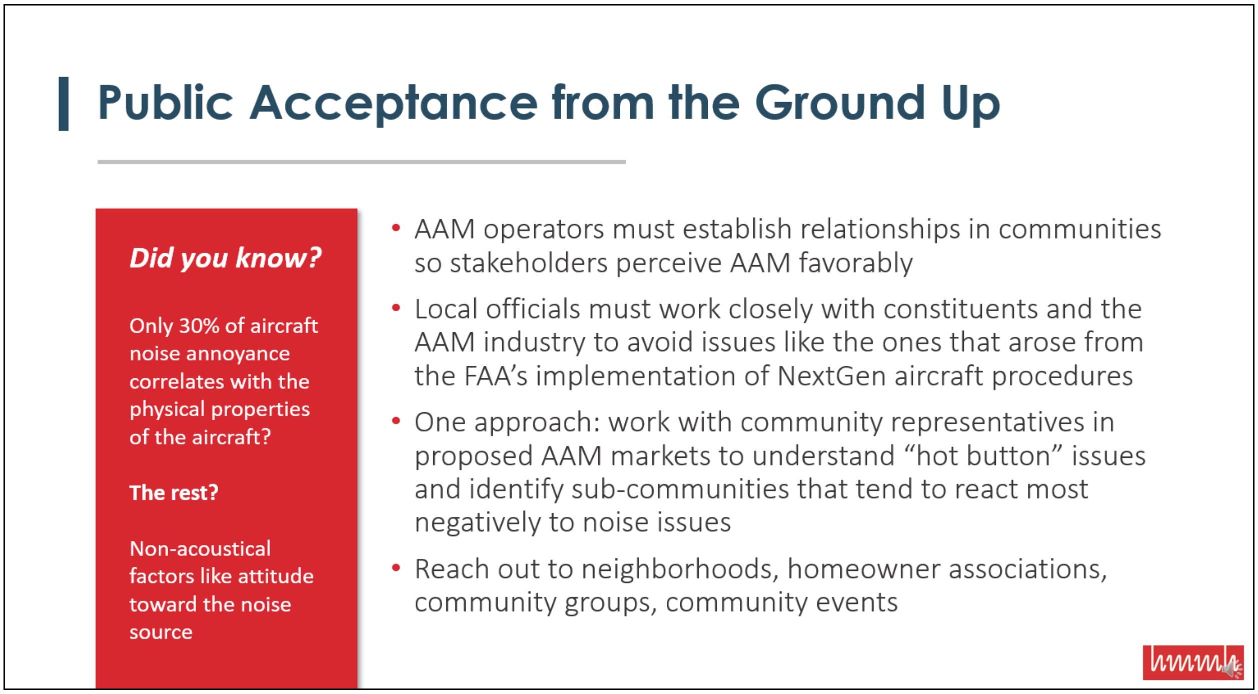


Figure 20.-1 *Public outreach toward gaining acceptance of AAM*

Figure 20.-2 *Develop tailored communication strategies*

21. Framework for Translating Noise Considerations Into Acceptable Zones for Vehicle Operations and Routing

John-Paul Clarke—University of Texas

Toward a new paradigm for air mobility operations in proximity to people's homes and workplaces, a possible framework is proposed for flight trajectory optimization that translates noise-related factors into suitable zones for operations and routing. Given that direct computation of noise impact within an optimization scheme is not scalable, innovative alternative approaches are suggested—including the use of mobile network data to help detail the acoustic terrain.

John-Paul Clarke, professor of aerospace engineering and engineering mechanics at the University of Texas at Austin, spoke about a concept and thought experiment toward developing a new paradigm for air mobility in the urban and regional space. He presented his framework for noise propagation considerations into acceptable zones for operations and routing to support optimization of flight trajectories from the standpoint of minimizing noise.

Clarke pointed out that vehicle designs for the advanced air mobility space are generally either helicopters or propeller-based aircraft that use their propellers to achieve short takeoff and landing (STOL) or vertical takeoff and landing (VTOL). He mentioned the examples of the Airbus CityAirbus, which is basically a quadrotor helicopter, and the early-concept Joby air taxi, with distributed propulsion. Aerial mobility aircraft are intended to achieve their short or vertical takeoff and landing in moving people or cargo near people's homes and workplaces. The proximity raises not only noise concerns, but also issues of safety and privacy—three concerns that often lead to noise complaints.

Trajectory optimization can play a key role within a toolkit for addressing community noise concerns associated with air mobility, and the issues of privacy and safety can also be considered as trajectories are developed that keep aircraft away from noise sensitive areas. Some basic information related to trajectory optimization is presented in Figure 21-1. The bottom line: Rotorcraft noise, and in turn community noise concerns, can be reduced by optimized trajectories for ascent and descent.

The effective management of noise concerns will rely on collecting data from experiments and creating aircraft performance models that account for the complexities of trajectories in urban environments, such as significant changes in thrust, attitude, and altitude that occur in short intervals and wind conditions in urban areas that do not exist in the free-field environment. Additionally, noise source models must accurately reflect directivity and frequency characteristics, and noise propagation models must fully account for transmission, reflection, refraction, diffraction, absorption, and scattering. Many of these factors are not considered in the modeling of noise from traditional commercial aircraft.

Ray tracing, addressed in Figure 21-2, is the most common method of capturing the noise impact of aerial and ground activity. Ray tracing models for aircraft can be combined with ones for ground vehicles to capture blockages. The technique can reveal blocked rays and show reflections off the ground and off buildings. Figure 21-2 provides an example of a cityscape and how rays travel and are blocked, along with an example of the acoustic signature within a city.

Ray tracing presents computational challenges, however: It is computationally intensive and direct computation of noise impact can be challenging. Clarke suggests a new optimization paradigm as depicted in Figure 21-3. Under this approach, noise thresholds are converted into 3D constraints for the locations where aircraft operate, and these noise constraints are converted into the equivalent of terrain to determine optimization for the direct trajectory.

Clarke next spoke about reciprocity, used to simplify the measurement process for many practical applications. The table in Figure 21-4 presents examples of reciprocity's applicability in mechanical, electrical, and acoustical systems. If one switches locations of a source and receiver, the reading will be the same, the speaker pointed out. Although the assumption for pure reciprocity assumes the medium is at rest, adjustments can be made for moving media.

On the next topic, geofencing, the speaker explained that virtual perimeters can be created to define areas where aircraft may not enter. The illustration in Figure 21-5 identifies a region's landforms such as hills, mountains, and valleys, which can render certain regions off-limits.

Given reciprocity's potential to reduce the extent of computations needed, Clarke became interested in whether other data could be used to support further characterization of acoustic terrain. He has collaborated with mobile network experts, as network operators have vast quantities of useful data. Ray tracing can be used in the propagation of radiofrequency waves from cell phone towers to city locations, and ultimately to develop appropriate coverage maps. These data may ultimately be used as a proxy to inform noise propagation, and related models and help improve outdoor sound propagation techniques.

Clarke noted that these factors can also be applied to consider privacy and other constraints on the ground. Together, factors can define the terrain for optimized solutions.

The speaker listed these takeaways in concluding his presentation:

- Trajectory optimization can reduce the noise impact of aerial mobility operations.
- Direct computation of noise impact within an optimization scheme is not scalable, and it is more efficient to convert desired noise thresholds into acoustic terrain and treat noise the same way as physical terrain.
- Mobile network (level-of-service) data could be used to develop acoustic transfer functions and ultimately characterize the acoustic terrain.

During a question-and-answer period, a participant asked whether the cell phone companies have models, validated with cell phone coverage data, that are publicly available. Clarke responded that, while the companies have a great amount of data, it is yet to be seen whether they can be motivated to share it. Asked next whether a different geofence would be required for each vehicle, Clarke stated that this is a possible scenario. In principle, he added, acoustic terrain could be developed for different vehicle types.

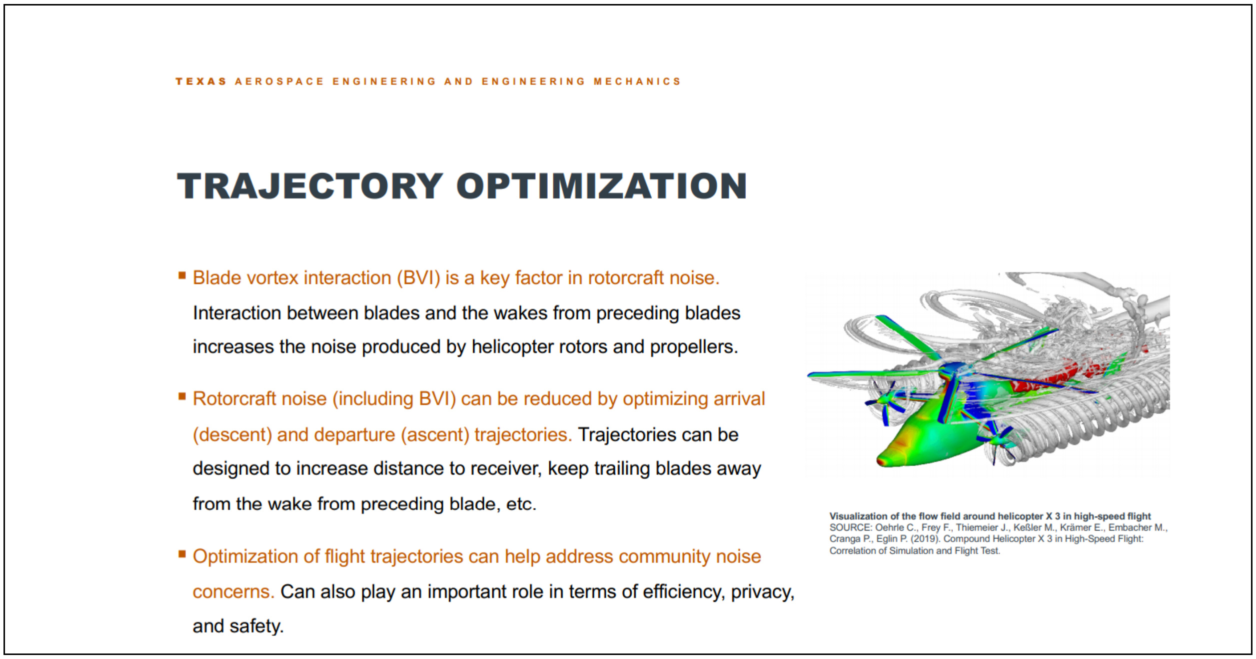


Figure 21-1 *Trajectory optimization*

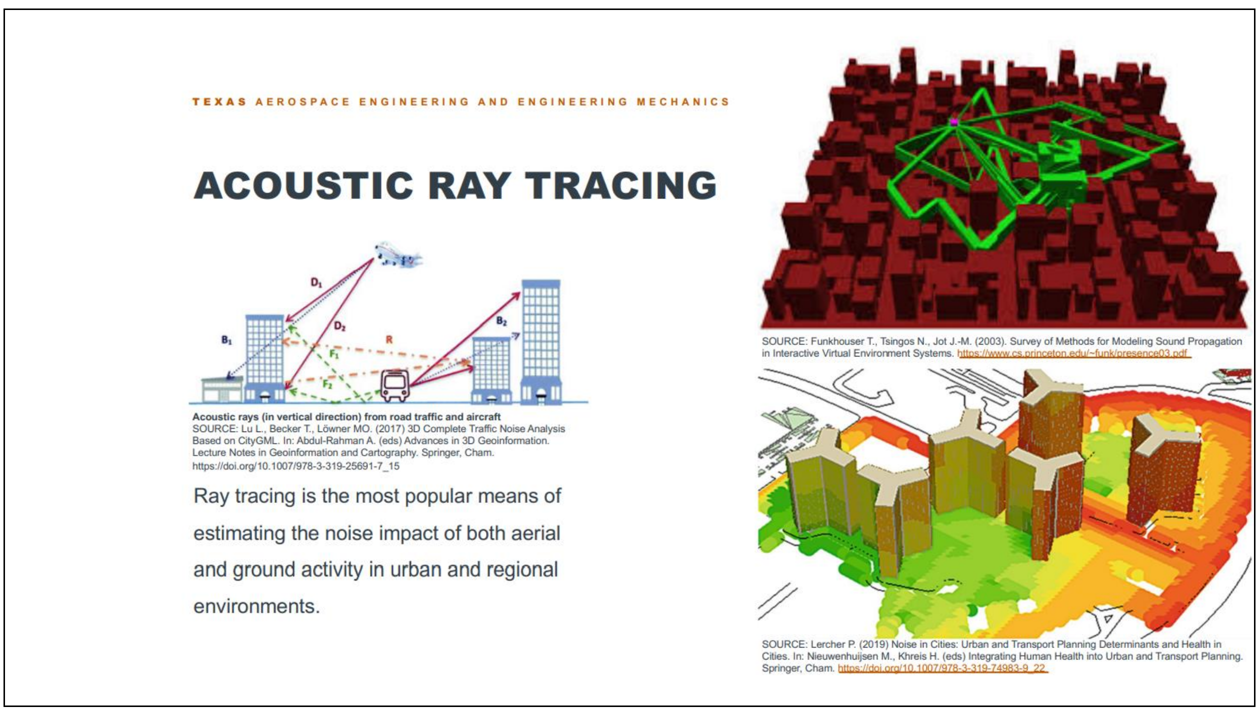


Figure 21-2 *Acoustic ray tracing*

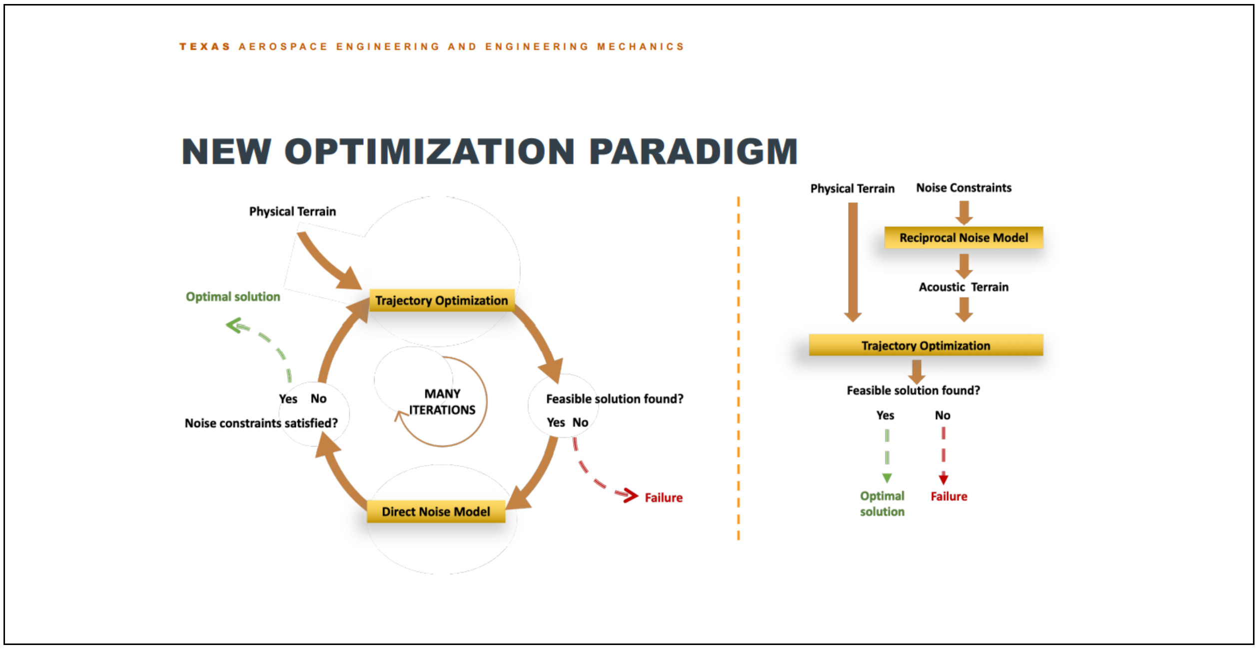


Figure 21-3 *Clarke's suggested new optimization approach*

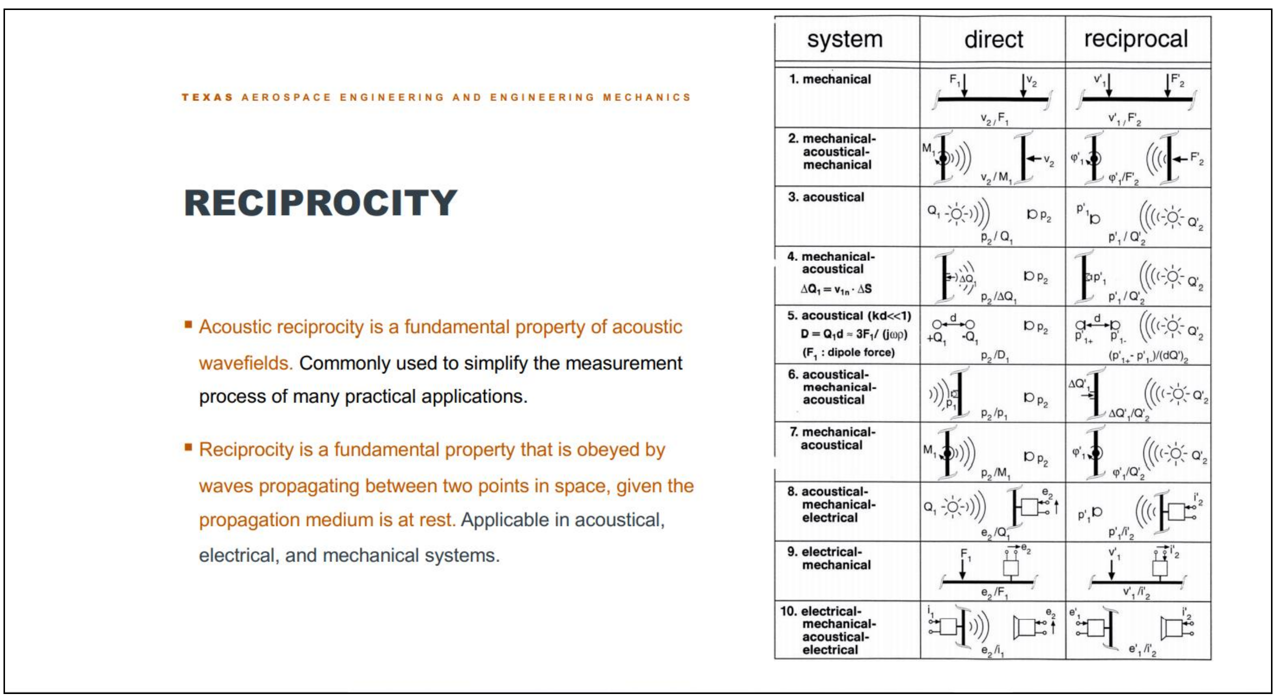


Figure 21-4 *Reciprocity*

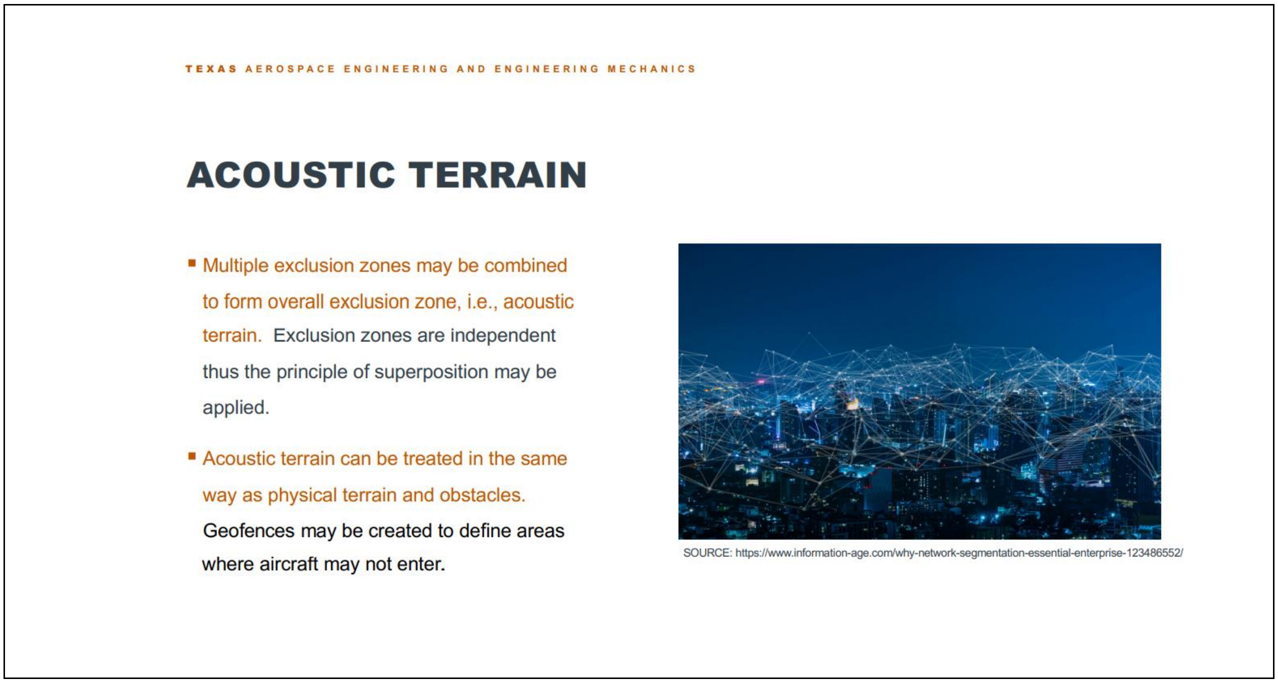


Figure 21-5 *Acoustic terrain as means of defining exclusion zones*

22. NATO Work on Progress for Reducing Propeller and Rotor Noise from Unmanned Aircraft

Philip Morris—Penn State

To provide a contemporary assessment of the noise from unmanned aircraft, as well as technologies for predicting and reducing UAS noise, NATO's Science and Technology Organization Research Task Group AVT-314 convenes distinguished experts from the United States and several other countries. Experts meet and share their knowledge on related topics, with a particular focus on propeller and rotor noise from UAS, and will integrate this knowledge into a technical paper expected to be published in 2022.

Penn State University Professor of Aerospace Engineering Philip Morris shared information with workshop attendees about progress made by the NATO Science and Technology Organization Research Task Group (RTG) AVT-314. The RTG's focus is "Assessment and Reduction of Installed Propeller and Rotor Noise from Unmanned Aircraft." The speaker mentioned that his presentation would serve as an update to his Penn State colleague Kenneth Brentner's presentation at the 2018 "Engineering a Quieter America" UAS workshop, during which Brentner discussed the same NATO group's plans as they stood at that time.

The NATO RTG objectives are to provide an assessment of the state-of-the-art in UAS noise prediction and reduction, and a technical assessment of the noise from UAS operations. The focus is on propeller and rotor noise, along with improved operational effectiveness in both the civilian and military contexts. Given these objectives, key topics include advanced approaches for measuring and predicting UAS propeller and rotor noise, and methods for reducing associated noise while maintaining a focus on the effectiveness of UAS operations. The RTG's deliverable is a technical report, to be published following the group's performance period officially slated as January 2019 to December 2021.

Research group participants represent the United States, Canada, the U.K., the Netherlands, France, Belgium, Denmark, Sweden, and Turkey. Figures 22-1 and 22-2 list each country's representative(s) and organizational affiliation.

Next, Morris reviewed the RTG's activities in the previous 1½ years. The Netherlands Research Lab in Amsterdam was the venue for a May 2019 meeting of the group. During this gathering, ONERA's Frank Simon discussed acoustic materials and also acoustic propagation and control of UAS. Christopher Schram spoke about a von Karman Institute-developed noise prediction code known as "Broadband and Tonal Models for Airfoil Noise," or BATMAN. NASA's Michael Doty and Stephen Rizzi updated the group on their agency's propeller noise research and the Urban Air Mobility Noise Working Group (UNWG). And Ulf Tengzelius from the KTH Royal Institute of Technology described his code associated with sound propagation in a realistic atmosphere. Also, during this meeting, the group agreed on report chapter topics and assigned chapter authors.

In October 2019, at a meeting in Trondheim, Norway, Penn State's Eric Greenwood gave a recorded tutorial about rotorcraft noise in maneuvering flight. Stephen Rizzi spoke about his NASA program focused on auralization and visualization, and in a second presentation, updated members on NASA's propeller noise research and the agency's UNWG. During this meeting, members also decided to focus their work on NATO Class I and Class II vehicles, which include those up to 600 kilograms.

At a virtual meeting in April 2020, the Netherlands Research Lab's Theo van Veen discussed aircraft noise auralization, especially in the urban environment, and Charles Wisniewski with the U.S. Air Force Academy spoke about the academy's propeller research. The group learned about NASA progress, as well, with one presentation summarizing a recent NASA Acoustics Technical Working Group meeting with a particular emphasis on UAS-related presentations; and a second updating attendees on UNWG workshops. ONERA's Frank Simon discussed noise reduction using a duct as a noise reduction device and active control processes applied to UAVs. And, Anant Grewal with Canada's National Research Council summarized ongoing and planned activities related to UAV noise in urban environments.

The group identified these as the prospective technical report chapters: Theoretical Background, Installed Propeller Noise, Community Noise and Human Response, Experimental Data and Measurement Techniques, Operations and Maneuvers, Sound Propagation, Propagation in Urban Environments, and Noise Reduction. Figure 22-3 lists these chapter titles along with lead expert(s) for each chapter.

An online meeting was slated for early February 2021, during which writing progress would be assessed, with the goal of finalizing the report by the end of 2022. Morris concluded by inviting workshop attendees to reach out to him with questions, or to contact him or Theo van Veen if they may be able to contribute information related to the report topics.

Figure 22-1 NATO *RTG AVT-314 participants (1 of 2)*

Figure 22-2 *NATO RTG AVT-314 participants (2 of 2)*

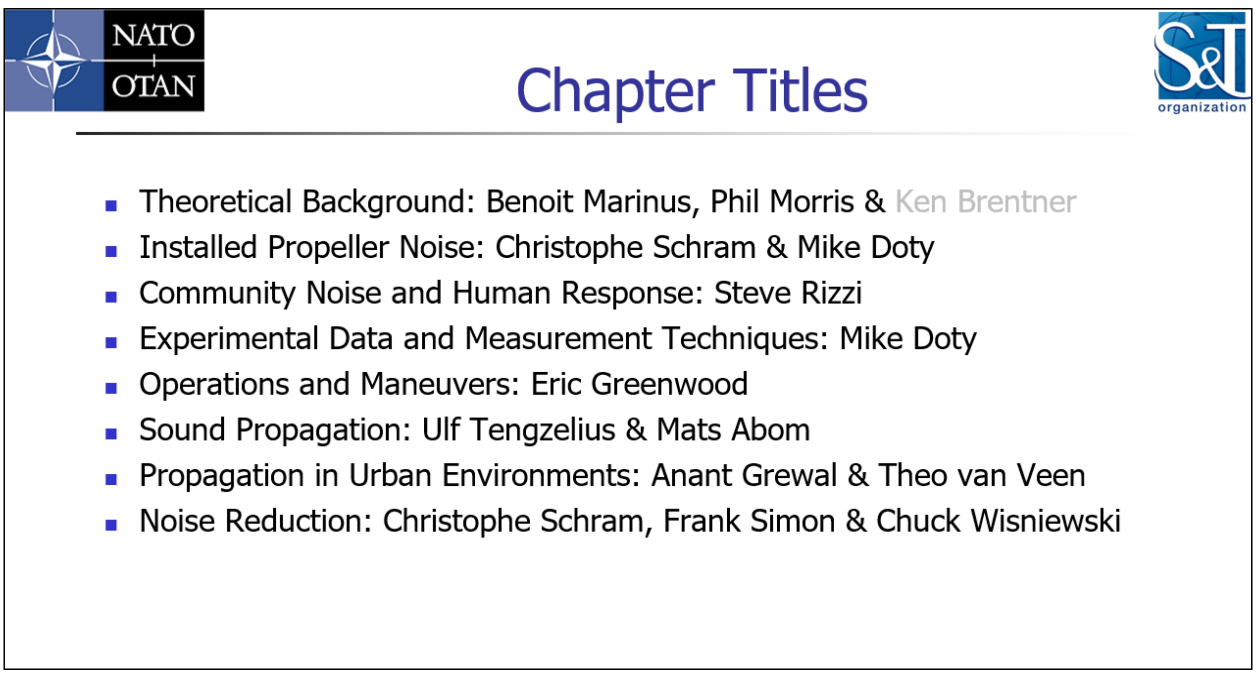


Figure 22-1 NATO *RTG AVT-314's technical report: planned chapters and lead experts*

23. From Helicopters to Quiet eVTOLs—A Manufacturer's Perspective on Noise

Julien Caillet—Airbus Helicopters

As the United States works toward integrating urban air mobility vehicles into the transportation landscape, Airbus Helicopters can offer valuable insights from an aircraft manufacturer's perspective. The company's lessons learned about air vehicle noise and its impact on communities can contribute importantly to the understanding of noise issues in the UAM context, for example.

As an acoustics expert with Airbus Helicopters, Julien Caillet spoke about urban air mobility noise from a manufacturer's perspective, first summing up the general objective of UAM as safely carrying passengers in congested cities, faster than—and with prices that are competitive with—ground transportation alternatives. He highlighted that the community impact from noise is a primary consideration for aerial mobility vehicle manufacturers and operators.

Helicopters are already involved in urban mobility operations, Caillet pointed out, providing examples including emergency and medical services and passenger transportation for both private and business uses. Given its experience flying over cities, Airbus is aware of communities' negative reactions to noisy helicopters flying overhead, and recognizes the significant obstacle this resistance represents.

Even as evolving technologies are offering new degrees of freedom for UAM, the challenge of noise remains and the question is raised, what are realistic targets for noise in the context of gaining community acceptance? For their part, helicopters are designed for a broad range of missions, including some critical ones such as military and search-and-rescue operations for which the quietest design may not be a priority. Still, helicopters are subject to strict noise certification requirements such as those contained in ICAO Annex 16. Noise requirements set forth in Chapter 8 of ICAO Annex 16 are the subject of Figure 23-1. As shown in the figure, noise compliance must be demonstrated for three flight conditions—take-off, flyover, and approach—with effective perceived noise in decibels (EPNdB) as the relevant metric and limits defined according to the aircraft's maximum takeoff weight.

A public database is available that allows comparisons of noise from different manufacturers' helicopters. The graph in Figure 23-2 shows Airbus helicopters (blue lettering) to be "very well positioned" compared with competitor vehicles, said Caillet, who stated that this is a reflection of the company's emphasis on designing quiet-as-possible products.

Caillet spotlighted some important observations about community response to noise, as summarized in Figure 23-3. Negative reaction has persisted—even increasing in many places—despite noise levels significantly lower than limits for certification. This points to a need for noise reduction under all operating conditions, not only those addressed in certification requirements.

Approach, takeoff, hover, and ground operations are major considerations for urban operations, he highlighted, while cruise flight is an important factor with respect to frequently used routes. The influence of background noise on community acceptance is another important issue for analysis, as is the role of "non-acoustic factors."

With UAM vehicles intended to fly at lower altitudes and in urban environments, reduced noise targets will be required compared with other aircraft. And, continuing on the topic of gaining community acceptance, Caillet mentioned that a range of variables are at play. Vehicle design, including propeller design, represents only a part of the equation, with control strategies such as low-noise flight procedures as another major factor.

A realistic evaluation of impact and annoyance is crucial toward identifying next steps. Estimating noise on the ground is advanced by appropriate source data from simulation, noise data from helicopters, and preliminary tests on UAM vehicles. The urban propagation effect must also be taken into account.

Figure 23-4 addresses design factors in the pursuit of the quietest possible vehicle design, which can be spurred by lower noise targets. New degrees of freedom are enabled by modern technologies such as distributed electric propulsion, which in turn are associated with advantages such as lower rotor tip speed and reduced engine noise. This progress brings new challenges for engineers, such as the need for new, validated prediction methods.

Given the inherent complexities of modern vehicle designs, Airbus has been leveraging the "demonstrator approach" to learn through experimentation. The company gained important knowledge from testing on the two demonstrators shown in Figure 23-5. The figure lists important findings, such as that flyover noise can be significantly reduced with the winged eVTOL, and that focusing on low-speed flight conditions could counter the significantly higher noise levels from tip speeds in hover compared to cruise conditions.

Caillet focused next on simulation through a multiple-fidelity tool approach. He highlighted the benefits gained from using a combination of tools, using the examples of empirical laws, fast simulation tools based on blade element models, and higher-fidelity methods for assessment of interaction and installation effects. Studies must be considered for the complementary information they provide about a vehicle overall.

Rotor propeller design is a key noise level driver, regardless of chosen architecture, the speaker emphasized, leading Airbus to conduct dedicated testing to assess the performance and acoustics of several rotor configurations.

In concluding his presentation, Caillet reiterated that noise is clearly a key consideration in vehicle design, and that both certification and operational noise requirements are being analyzed toward arriving at an appropriate target noise level.

In response to a workshop participant's question about metrics used in the assessment of community noise impact, Caillet said Airbus is considering various metrics, but that the company currently relies on conventional metrics such as Lden, LAmax, and SEL. Achieving the goal of incorporating background noise data into a formula is "very difficult," he stated, adding that the research community may be in a better position than manufacturers to develop these types of helpful metrics.

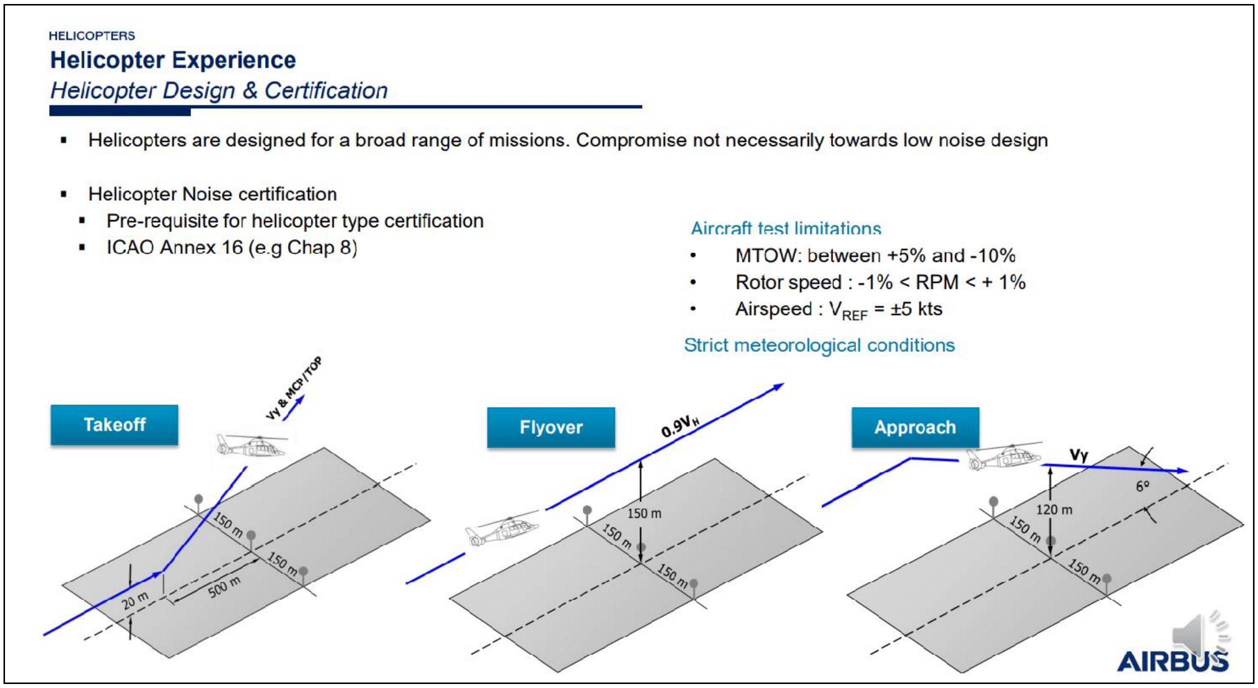


Figure 23-1 *Helicopter noise compliance must be demonstrated for three flight conditions*

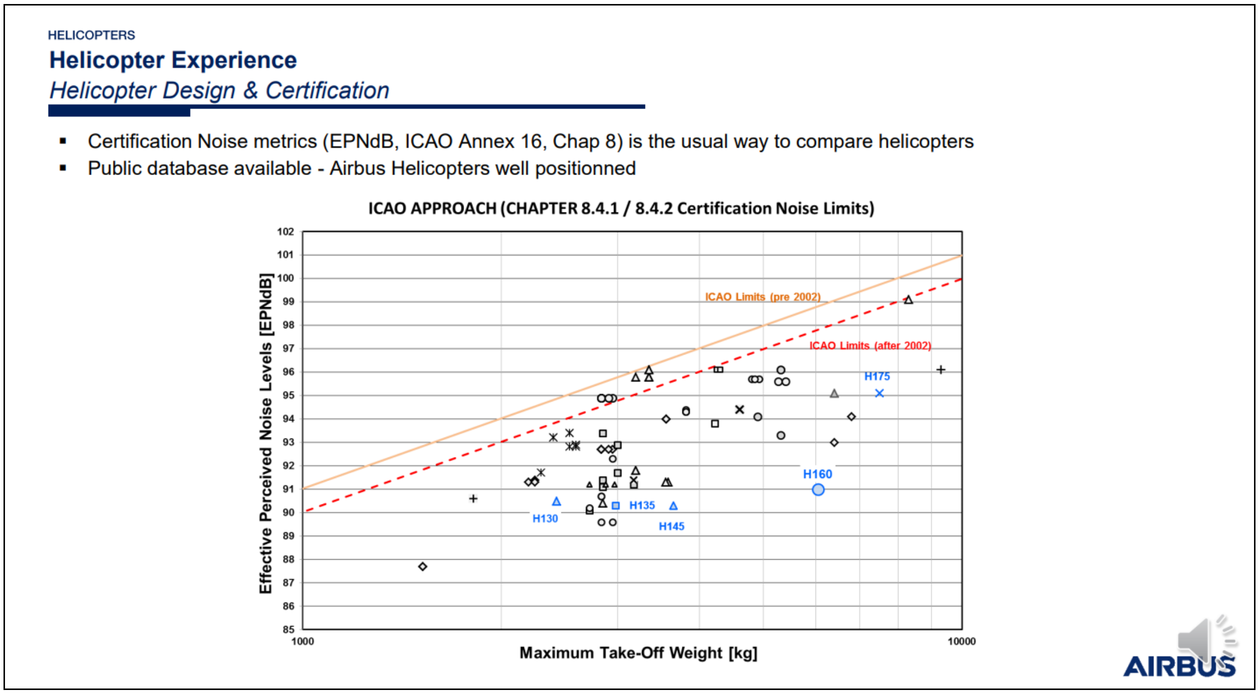


Figure 23-2 *Comparing noise from different companies' helicopters*

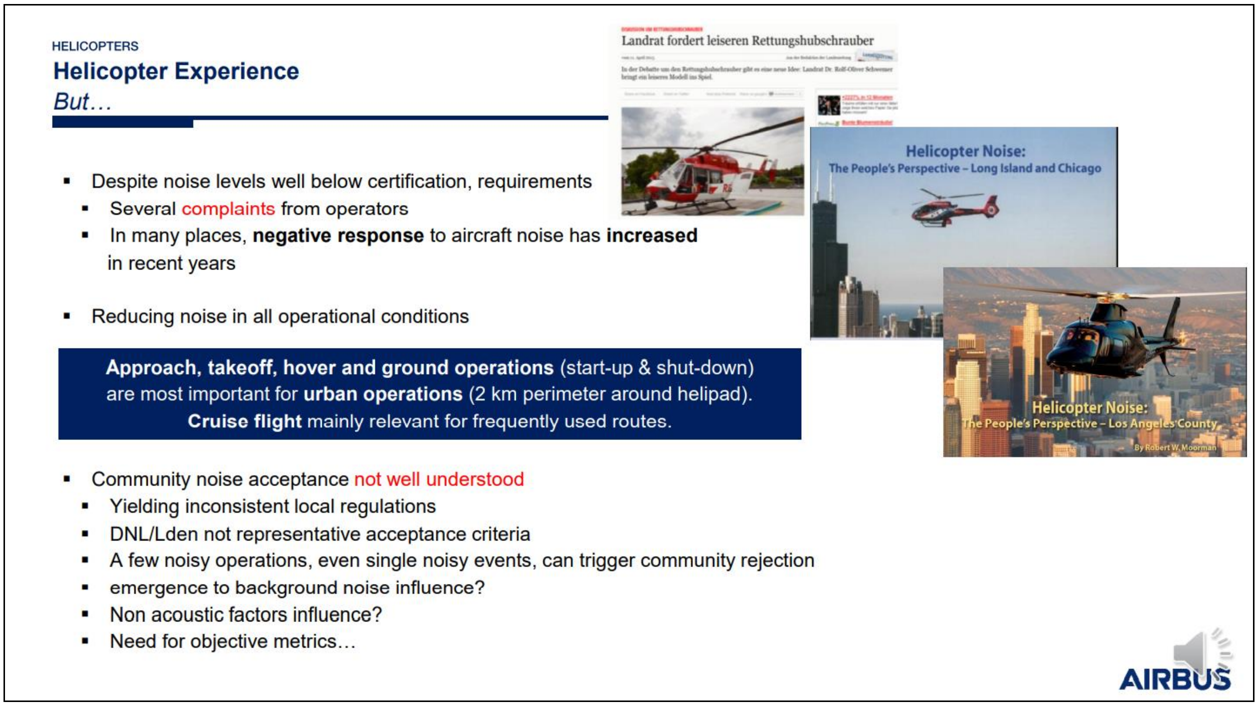


Figure 23-3 *Many factors influence community response to noise*

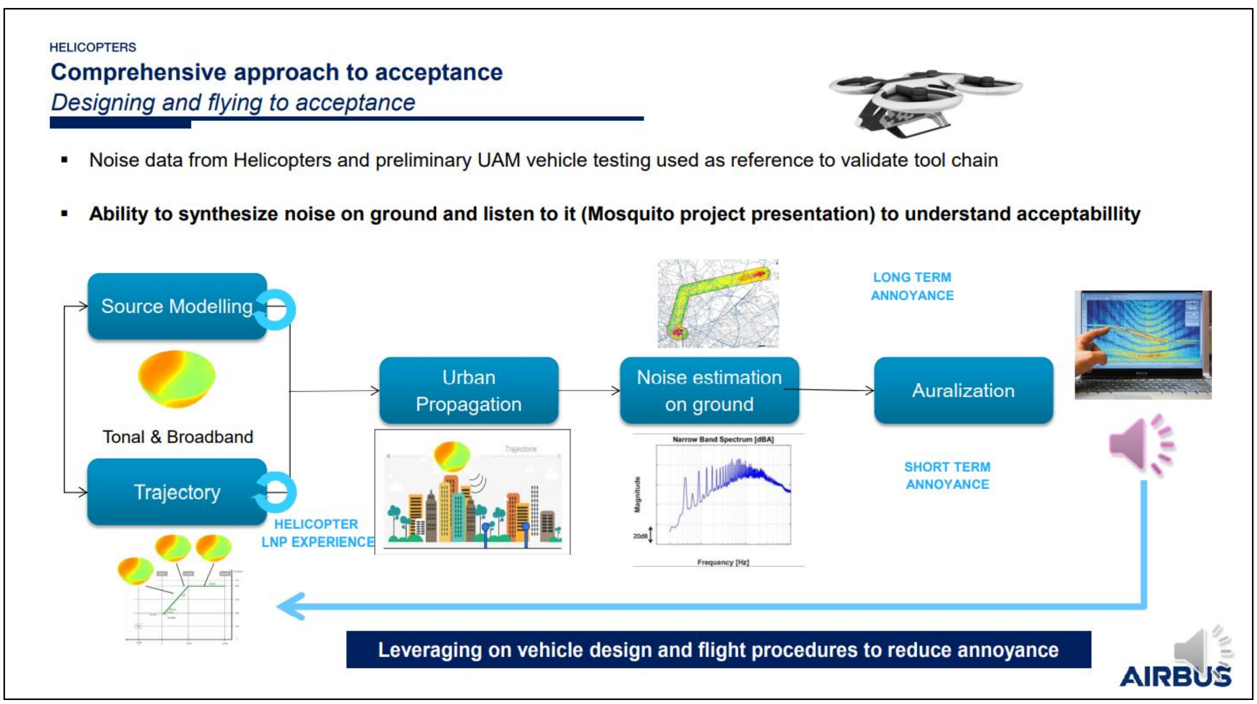


Figure 23-4 *Design-related factors for reducing noise to increase acceptance*

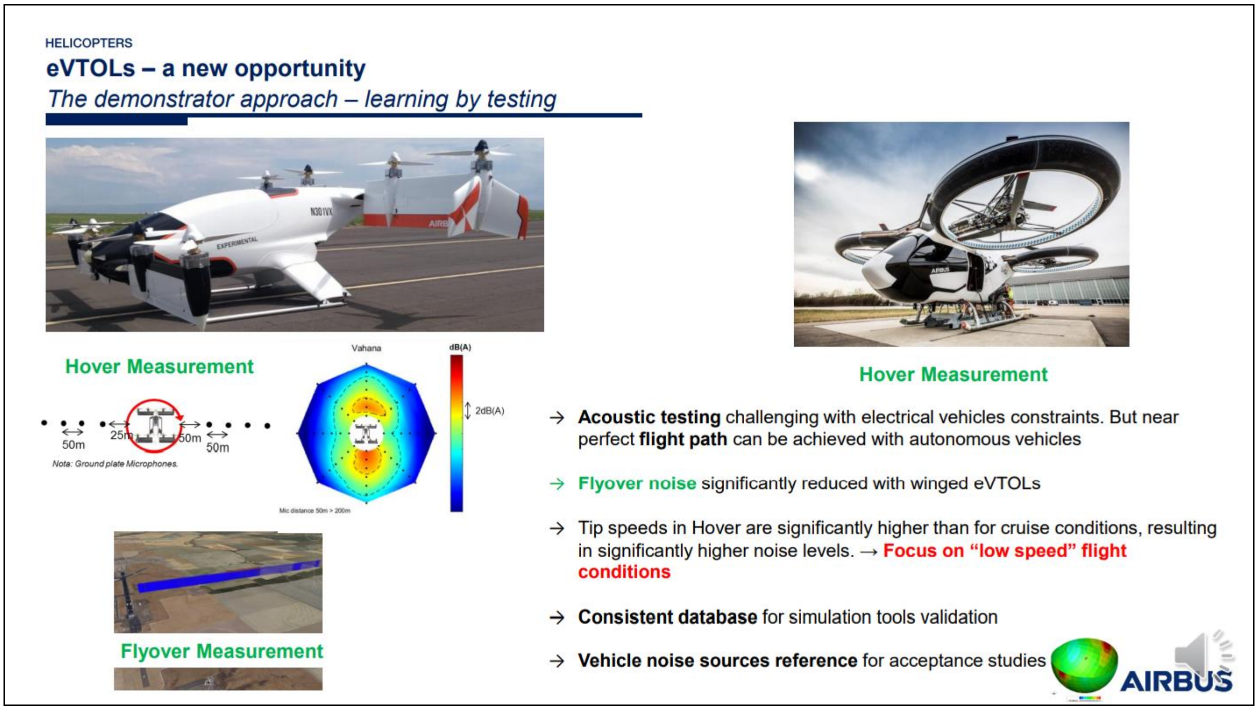


Figure 23-5 Demonstrators bring to light important information about noise

24. First Principles and Noise Considerations for Novel Air Vehicle Design

Brian Yutko—Boeing NeXT

Emerging air vehicles with electric propulsion systems rely on diverse design elements with promise in terms of noise and the environment more broadly. For example, electric VTOL aircraft can reduce noise and, in turn, diminish annoyance, among other benefits.

Brian Yutko, Chief Technologist at Boeing NeXT, spoke about first principles of design for a new class of air vehicle enabled by alternative propulsion systems. Yutko came to Boeing via acquisition of Aurora Flight Science, to lead in the exploration of these types of pioneering mobility solutions.

This emerging class of novel air vehicles is reflected in Figure 24-1, which shows maximum takeoff weight (MTOW) as a function of range for:

- Multicopter design with no wings that flies entirely on hover lift
- Separate lift-and-cruise-winged electric VTOL aircraft
- "Tilt-something eVTOLs" that combine lift propulsors and cruise propulsors into a complex, generally tilted arrangement
- Electric super-short takeoff and landing (eSSTOL) vehicles
- Hybrid eVTOL concepts.

These emerging vehicle classes are interesting for their market potential as well as their electric propulsion systems with the promise of greater sustainability.

The presenter homed in on the electric VTOL configuration, including its effects on noise. Figure 24-2 shows an electric vehicle configuration, with the left-side plot highlighting a general trend: Larger rotor area for a same-sized vehicle reduces the hover power required and reduces motor size, among other benefits. The right-side plot reveals, at the bottom line, that a configuration with a more complex tilted orientation is associated with lower cruise power. Summing up, Yutko explained that a design can benefit from balancing hover and cruise power requirements. Figure 24-3 highlights a series of novel subsystems in the categories of "sensing," "computing," and "engine" that in turn are supporting a proliferation of new vehicles entering the market.

After briefly introducing tools and methods for noise simulation and prediction, the presenter talked about first principles analysis in the context of noise as it relates to configuring these emerging air vehicles. Electric VTOL noise is dominated by the propulsion system in hover, he stated. The design has largely removed engine and motor noise, with other elements—such as blade geometry, disc loading, blade count, reflection, turbulence, multirotor interactions, and tip speed—becoming the main sources.

The speaker next discussed a simple study of an electric VTOL evaluating three main factors—disc loading, tip speed, and blade count—to identify tradeoffs. Figure 24-4 details findings relating to these levers for noise reduction in the electric VTOL and shows that a reduction of 12.5 dB in the overall system noise is possible as shown in the bottom right quadrant. Additional levers are also available to designers, however. As summarized in Figure 24-5, these include elements related blade geometry, such as sweep, thinning of blades, and asymmetrical blades; ducts and shrouds, used in some concepts for their ability to absorb noise with acoustic liners and to deflect noise in non-sensitive directions; and the multirotor design, by configuring rotors for noise benefit.

Yutko noted that all these levers have system-level effects on the aircraft's performance that must be considered. For example, ducts and shrouds increase drag and weight, which, among other effects, can increase the overall system size and require a larger motor. Figure 24-6 summarizes some performance effects of low-noise design.

Noise is much more than decibels, the speaker then recognized. While models can capture the physics of noise, annoyance is complicated and subjective. Figure 24-7 addresses important concepts in this regard: Noise sensitivity is frequency-dependent, with perceived loudness depending on frequency content; the differences in noise levels are more important than absolute values; and noise backgrounds and interactions can result in complex contributions to perception.

Yutko also discussed the Figure 24-8 frequency spectrum plot for a helicopter versus a winged eVTOL, in a hover condition at about 50 meters in altitude. He highlighted the very high and low frequency peaks identifying the helicopter's whop-whop noise. The frequency content for the winged eVTOL is much higher than the helicopter's, the speaker pointed out, which sometimes and in this case is still below the background noise in urban and suburban environments. Yutko described his own perception of the helicopter flyover as "very annoying and intrusive"—even disruptive for performing his team's flight test underway—while the electric VTOL aircraft was "much more random and much less annoying."

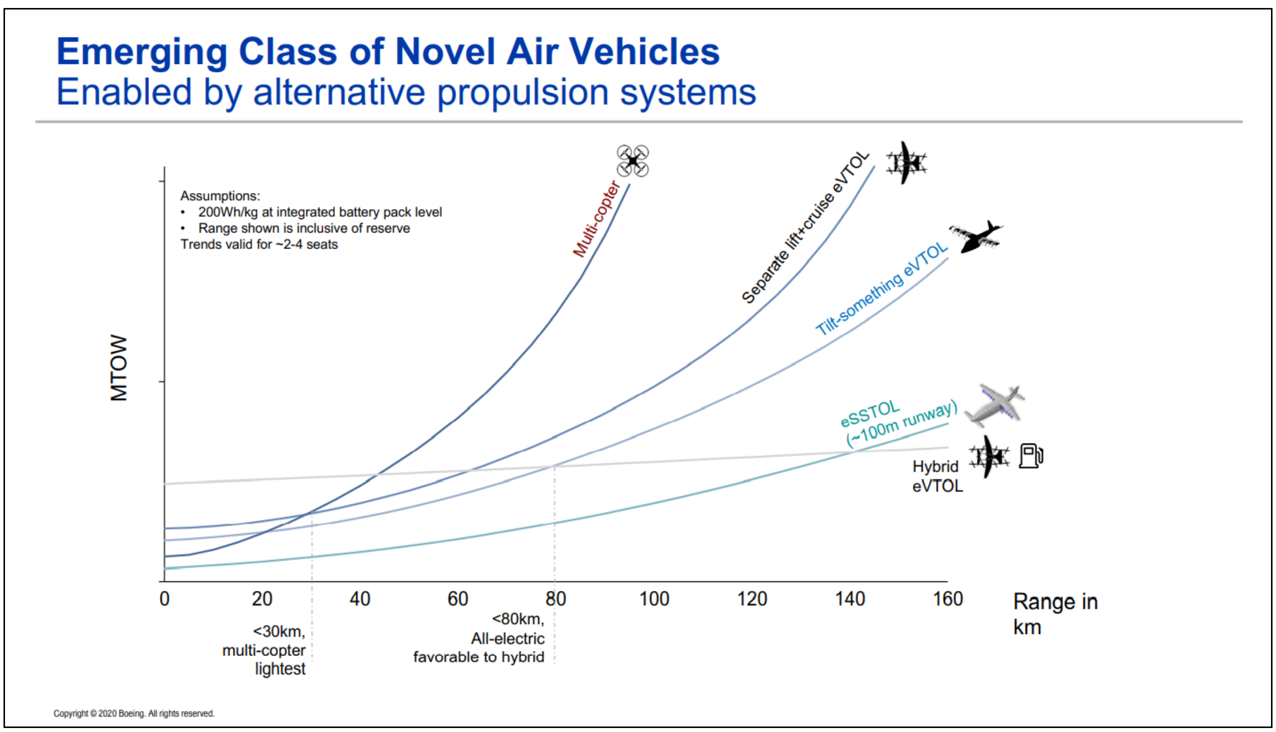


Figure 24-1 *Emerging class of novel air vehicles*

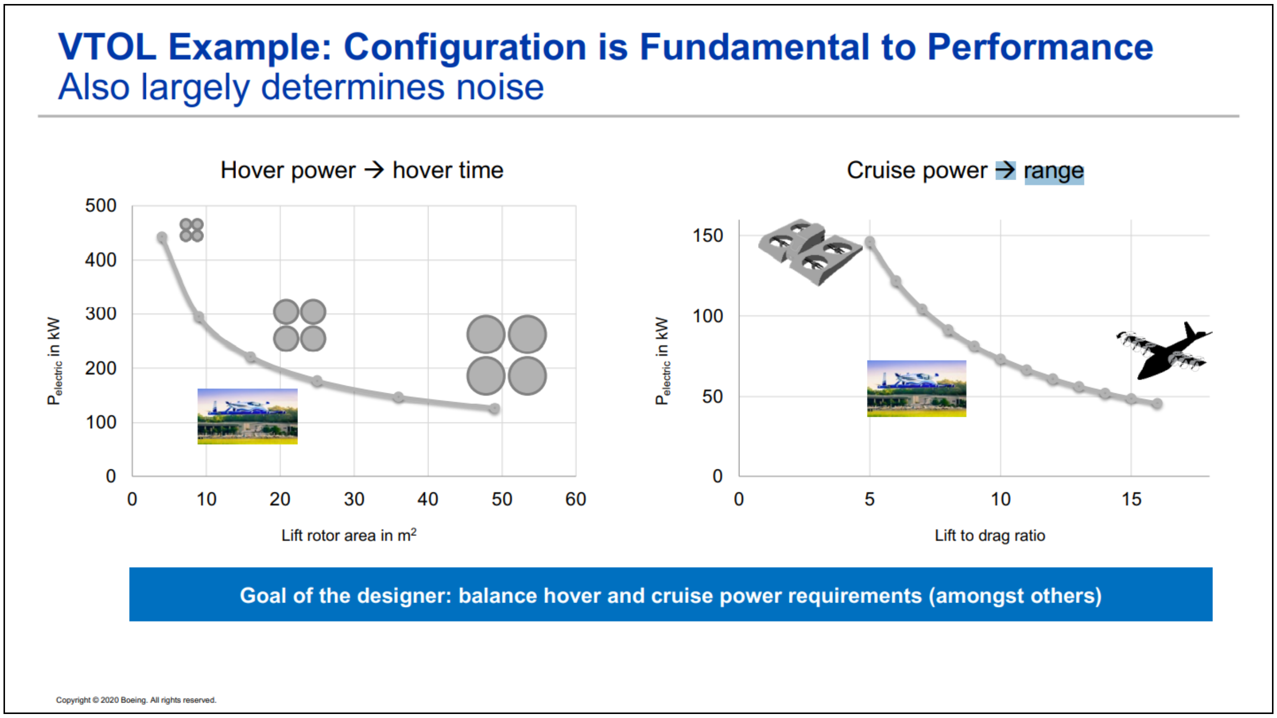


Figure 24-2 Configuration influences performance, noise

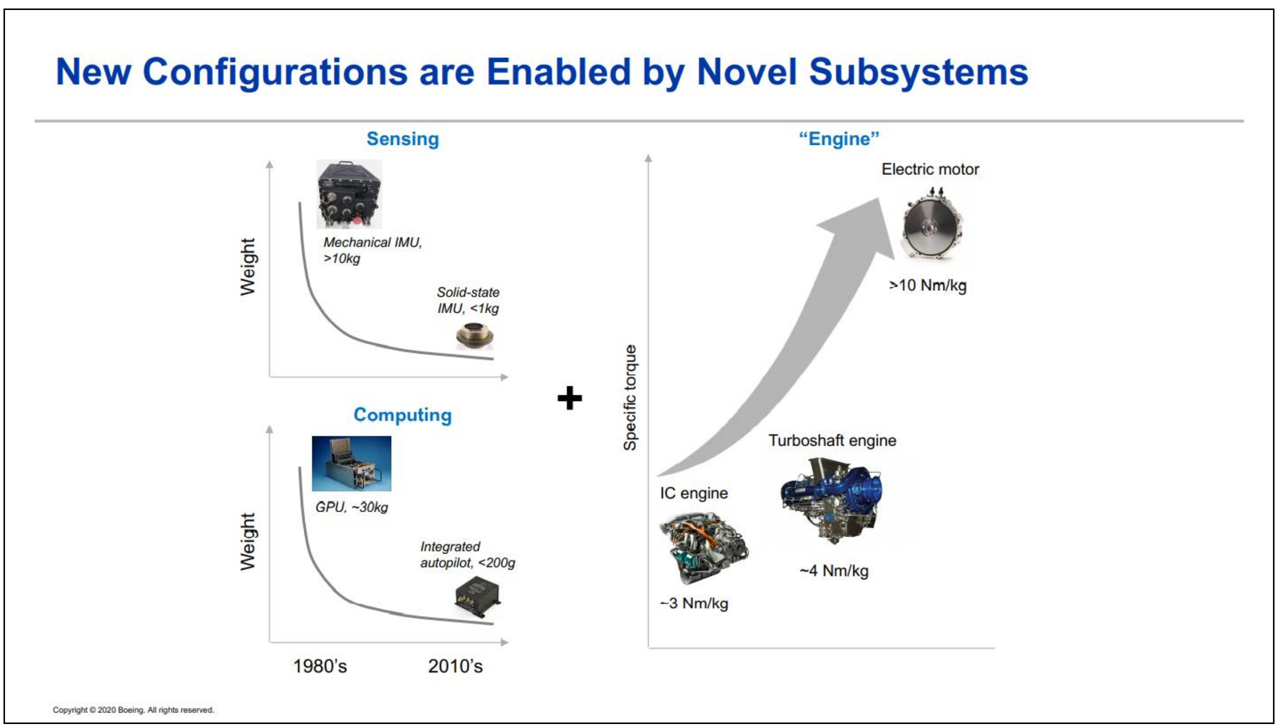


Figure 24-3 New configurations are enabled by novel subsystems

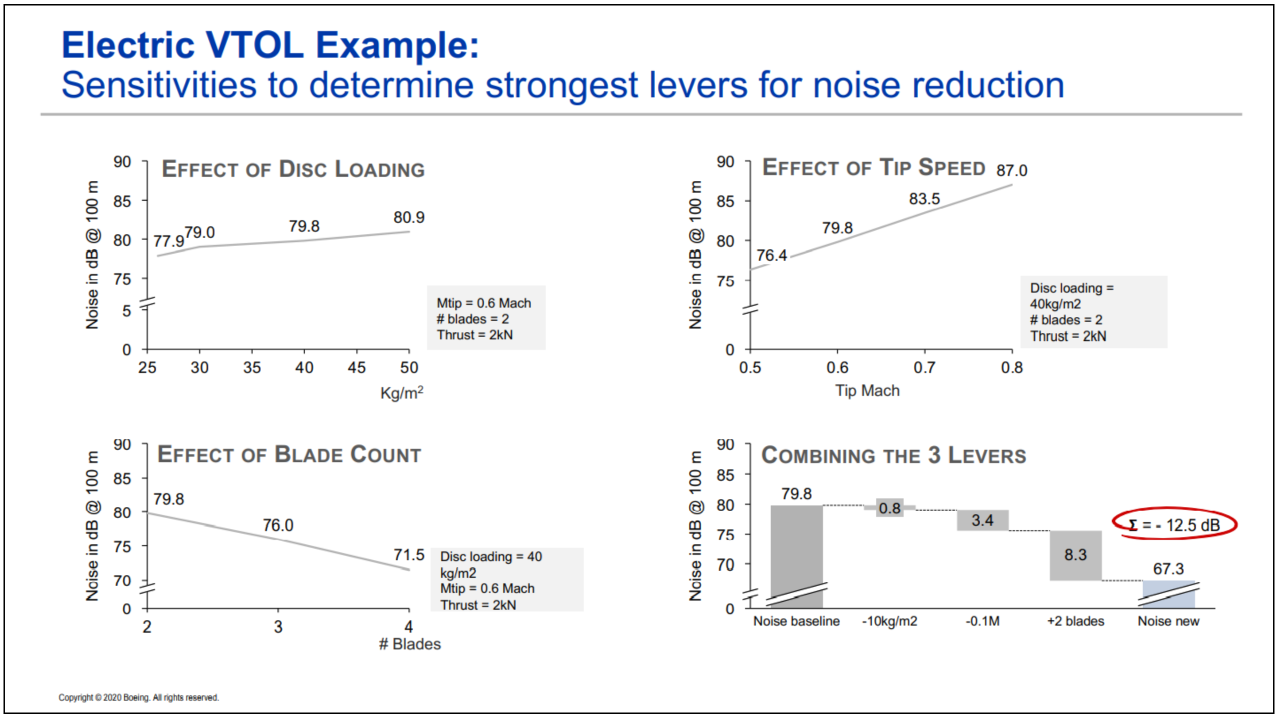


Figure 24-4 *Strongest noise reduction levers for eVTOL*

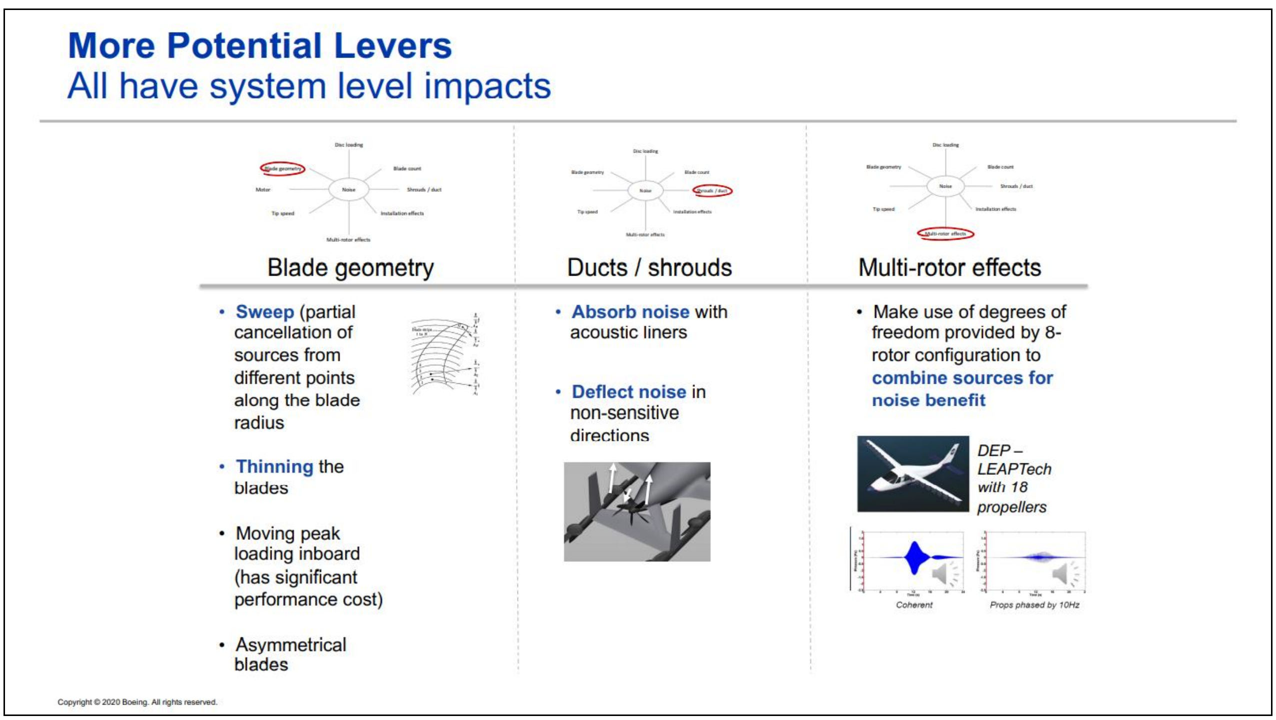


Figure 24-5 *Additional potential levers exist for managing noise*

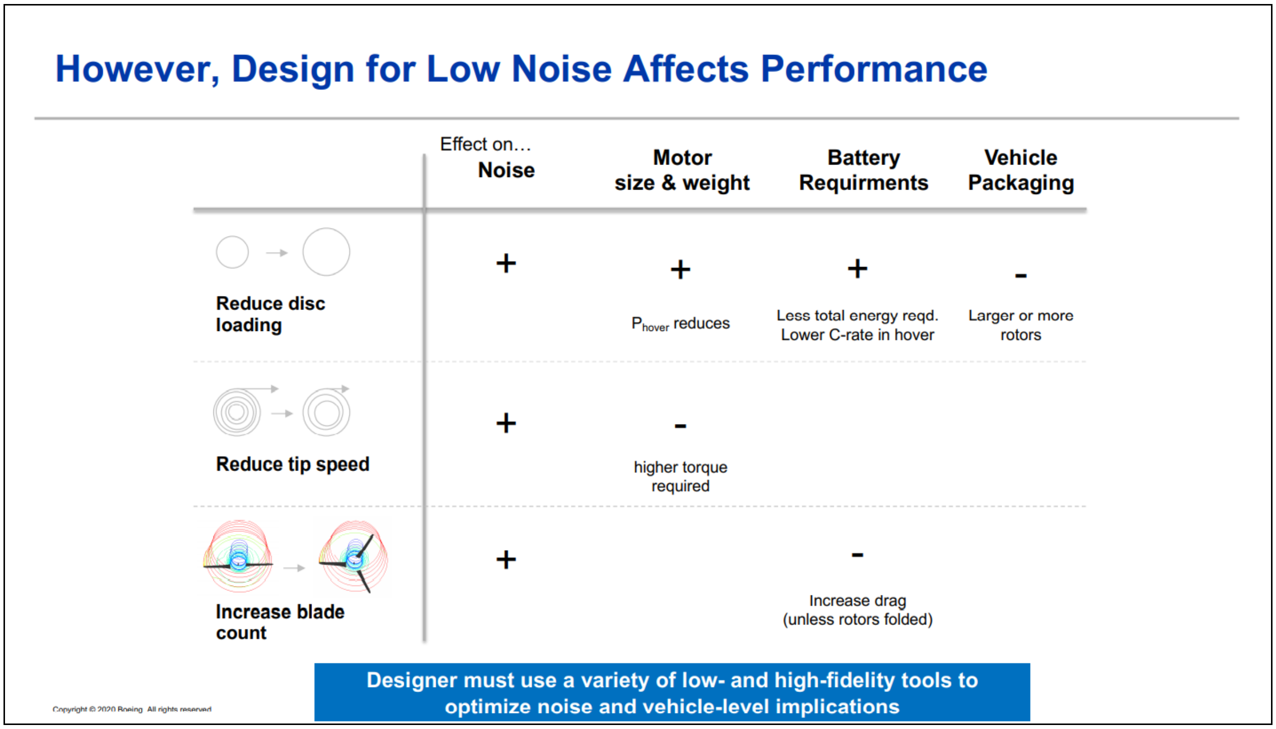


Figure 24-6 *Design for low noise affects performance*

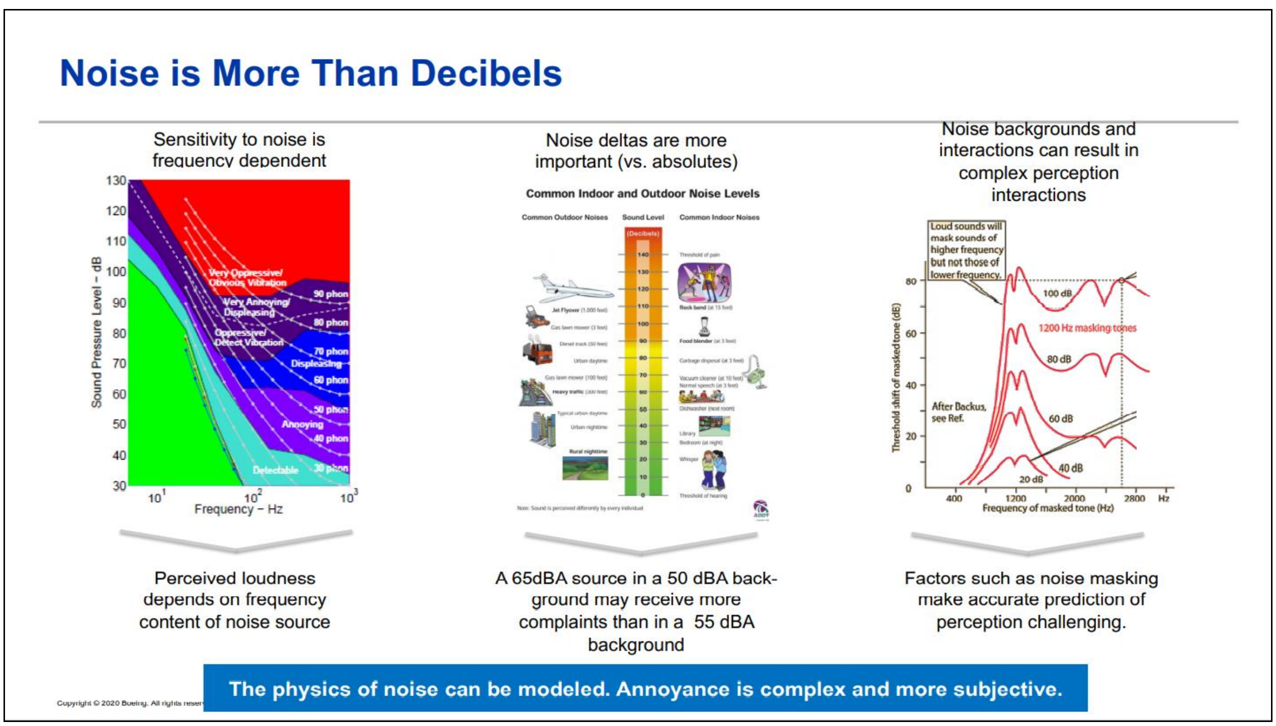


Figure 24-7 *Noise is more than decibels: annoyance is complex and subjective*

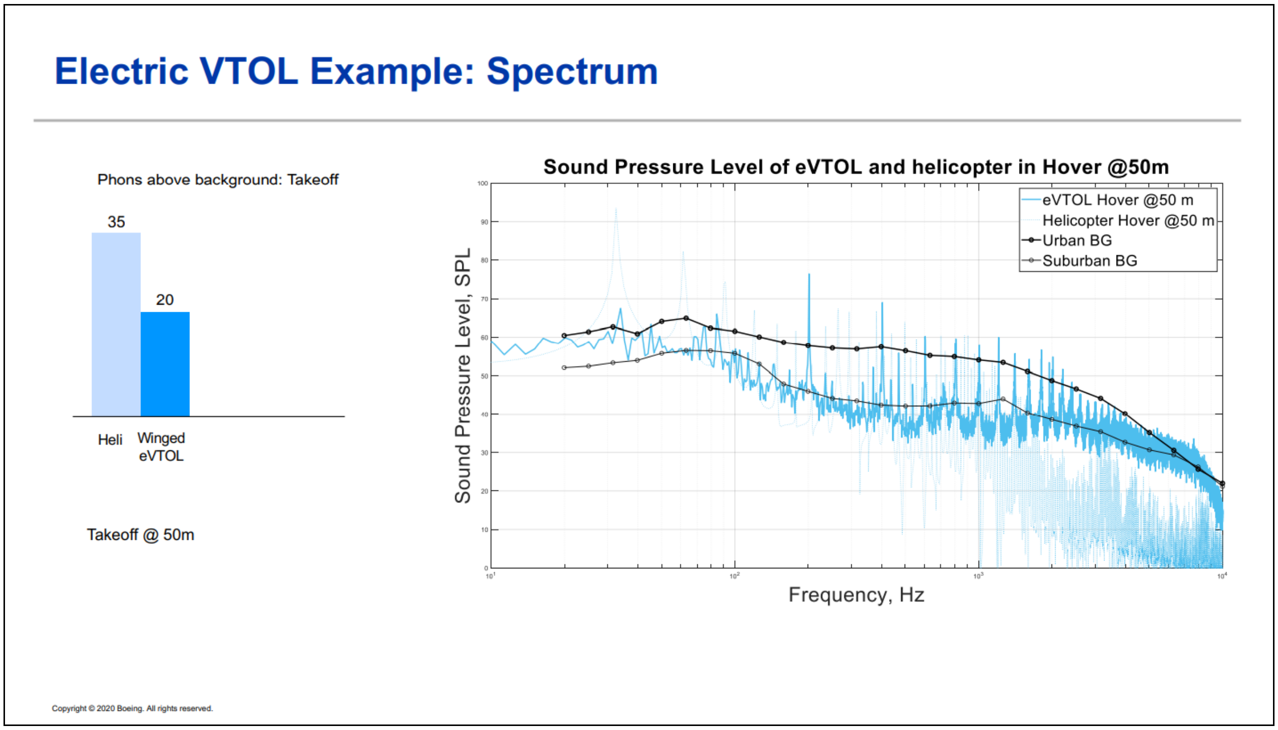


Figure 24-8 *Comparison of helicopter and eVTOL noise*

25. Recent Work of ANSI S12/WG58 on Small UAV Sound Measurement

Kevin Herreman—Owens Corning

Working Group 58 of ANSI's S12 Committee is developing standards for measuring sound power emission from small UAS, and issues such as recirculation have raised concern in the context of testing rotary-wing UAS in an anechoic chamber. WG58 and Owens Corning are working to identify methods for managing this type of hurdle, as they establish an appropriate standard for these rotary-wing UAS, as well as for fixed-wing vehicles.

Kevin Herreman, principal acoustic scientist at Owens Corning Corporation, discussed the recent work of the ANSI accredited Acoustical Society of America standards committee S12 Working Group 58. This working group, chaired by Herreman has about 30 members, was created in 2017 to develop and maintain a new standard for the measurement of sound power emission from small (under 55 pounds) unmanned aerial systems (UAS).

A foundation is provided by Owens Corning's work for the Air Force Research Laboratory (AFRL) that measured sound power emitted by unmanned aerial vehicles in an anechoic chamber and compared this measurement to data gathered at AFRL's remote testing facility. A viable measurement was determined based on several tests, and this measurement became the basis for the standard being developed for those wanting to determine UAS sound levels.

The standard has these additional goals in mind:

- Repeatable and independent of the environment
- Characterized by a uniform test procedure following specified operating conditions
- Capable of providing UAS sound power level data that can be used to model sound pressure levels at ground locations using existing modeling technology.

Herreman presented a history of the working group's activities, as summarized in Figure 25-1. Early efforts were focused on validating the scope of the standard. While little issue was found with fixed-wing UAS testing in an anechoic chamber, there were concerns for testing of rotary-wing vehicles inside the chamber. NASA research on the pros and cons of testing outdoors versus indoors, for example, identified recirculation as a primary concern in an anechoic chamber. Given that the concerns were limited to rotary-wing UAS, it was decided that WG58 would develop a rotary-wing vehicle standard separate from the standard for fixed-wing UAS.

Before sharing the specifics of WG58's steps in 2020 to address the recirculation concerns for rotary-wing UAS, Herreman mentioned a related working group discussion about the newly adopted European regulations on small UAS, including testing approach. The measurement process used in the development of these European regulations was considered to be "fraught with issues," the presenter stated, especially with the test item's proximity to the ground plane, and the working group determined not to use this measurement method.

As for progress in 2020, Herreman noted that COVID-19 interfered with some plans for the working group to meet in that year, but that a virtual meeting took place about two weeks after the current workshop, on December 18, 2020.

During 2020, Owens Corning focused on anechoic chamber testing, and the challenge of recirculation, in particular. The Owens Corning team investigated the effect of adding a porous media on the floor of the chamber directly under the downwash from the test item's blades to diffuse and reduce the flow of the high-velocity air coming from the test item. As shown in Figure 25-2, to the right of a summary of WG58 progress in that year, the unit was suspended in the fully anechoic chamber, while a porous media on the floor took in the high-velocity air coming from the rotor downwash, diffusing the energy and slowing the air down. This allowed the air to recirculate up through the chamber and then come down through the propellers. Herreman said, "This isn't a complete solution, but seems to provide a manageable effect." At frequencies below those of the rotor blade,—around 250 Hertz, for the particular test item—the material on the floor reduced overall noise of the unit, and made the measurement much more repeatable.

Following up on these findings, Herreman's Owens Corning team took multiple measurements and reported the results in a paper presented at NOISE-CON 2020. Under the conditions in their testing, the group found virtually no difference between the 20-microphone array measurement and the 40-microphone measurement in overall sound levels, or within the one-third octave bands. However, a much better spatial recognition of the sound sources was seen with the 40-mic array. Additional work was underway by Frank Mobley, who was using data from the 20- and 40-mic arrays to analyze and to model the systems, and was using some simulation programs to predict noise and geographic location.

Herreman concluded his presentation by discussing WG58's plans for 2021. A draft standard for fixed-wing UAS could be available by the end of 2021. The group would continue work to define how testing is done for a rotary-wing standard, including the consideration of whether indoor or outdoor testing represents the best option based on benefits and downsides of each. While Frank Mobley works on the model prediction angle, the Owens Corning Acoustics Research Center is focusing on outdoor testing.

Following his presentation, the speaker responded to a workshop attendee's question about whether WG58 coordinates with the Federal Aviation Administration. The group was working to restore FAA participation, he said, after the retirement of a working group member representing the agency.

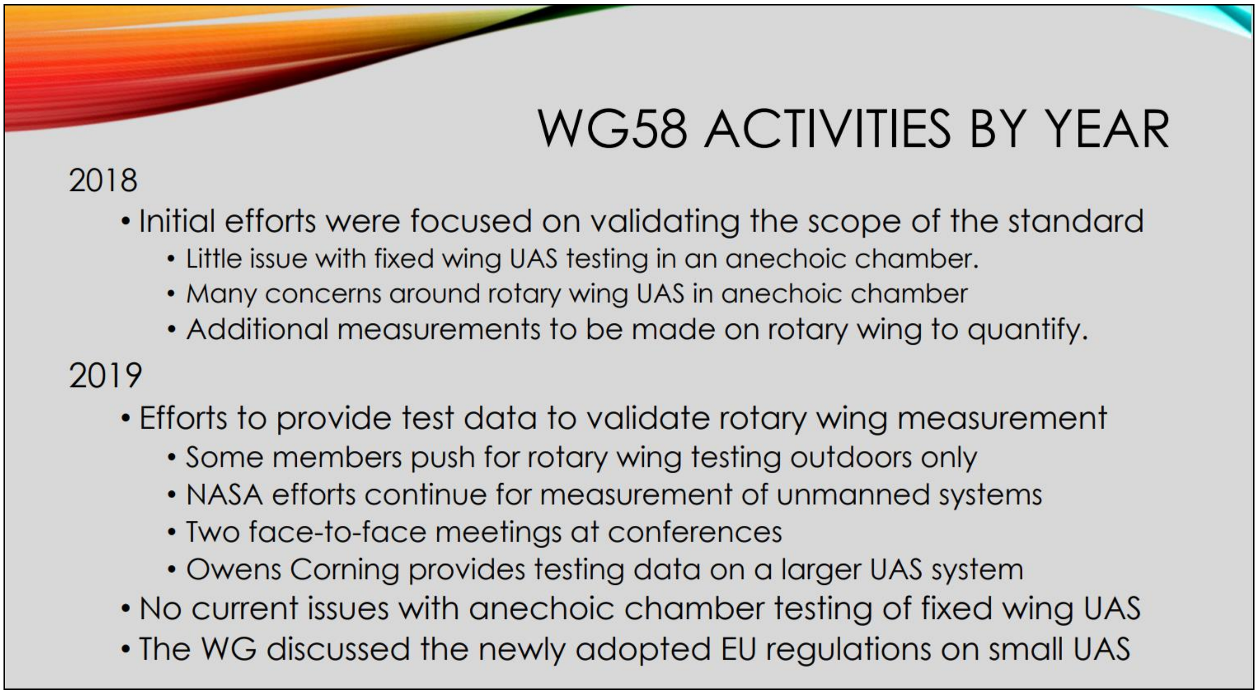


Figure 25-1 *S12 WG58 activities in 2018 and 2019*

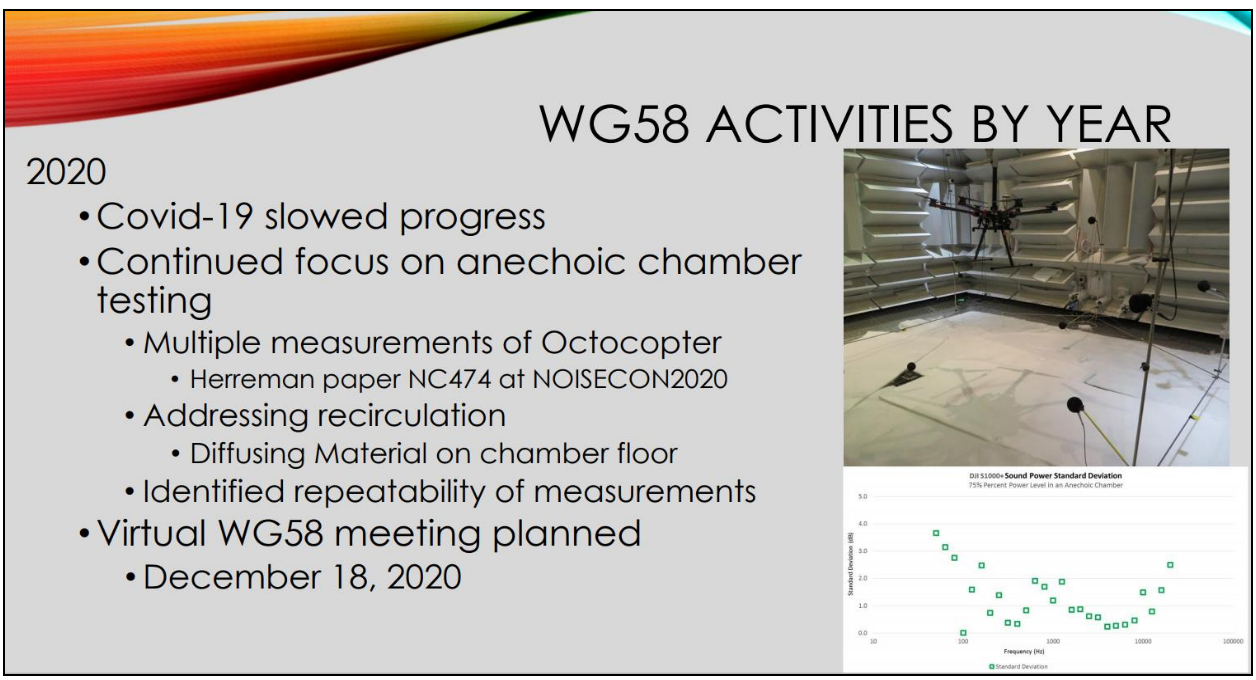


Figure 25-2 *S12 WG58 activities in 2020*

26. Small UAS Noise: Policy and Technology Considerations

Javier Caina—DJI

The European Union has adopted regulations designed to limit noise from small UAS. Are these regulatory measures appropriate—needed to protect people against disturbing noise from these increasingly popular vehicles—or do the rules represent unnecessary overreach where no problem actually exists?

DJI Director of Technical Standards Javier Caina spoke from his company's perspective about noise from small UAS. DJI has grown from a single small office in 2006 to a global business with operations spanning the Americas, Europe, and Asia with projects across industries including those in Figure 26-1. "Our revolutionary products and solutions have been chosen by customers in over 100 countries," he said, adding that drones have rescued hundreds of people from peril worldwide.

According to the FAA, more than 1.7 million drones are registered in the United States. In 2019 small UAS racked up more than 10 million flight-hours in this country. Despite these vehicles' popularity, a DJI review of more than 1,000 state bills in the U.S. since 2018 identified none dealing directly with noise from a drone, which the presenter said raises the question, "Is there really even a problem with drone noise?" Caina recognized, however, that concerns had been raised of late based on the repetitive flights, larger aircraft, and other characteristics of some drone package delivery operations.

The presenter discussed some technological upgrades by DJI in recent years to reduce noise from its aircraft, including a change to the propeller shape, a new propeller tip design, and replacement of the brushless DC electronic speed controllers (ESC) with the quieter field-oriented electronic speed controller ESC. Figure 26-2 presents DJI aircraft sound power levels compared to the EU maximum sound power limits.

Caina explained that the European Union Commission Delegated Regulation EU 2019/945, as amended by EU 2020/1058, defines the maximum sound power level for UAS in the "open category." Additional details of the European regulation are presented in Figures 26-3 and 26-4. Caina said that Europe took regulatory action prematurely and "without any indication of an actual problem," at a time when "we do not think the noise of a small UAS has caused complaints anywhere in the world."

Several regulatory and standardization challenges exist in EU 2019/945 according to findings by a ASD-STAN (a technical body to the European Committee for Standardization CEN) Technical Report Noise group, including the issues listed in Figure 26-5. Examples of these issues are: the sound level of hovering does not reflect noise during operations; sound power limits for drones are lower during typical drone operations at 30 to 120 meters than for other machines which operate closer to people; drones that are too quiet may fail to alert people of vehicles flying in the area, possibly undermining social acceptance and raising concerns about "spying" on people; and measurements according to ISO 3744 shall be acceptable as its accuracy level is appropriate for small UASs.

Caina presented some concluding thoughts about EU regulation of small UAS, stating that the current European regulation requires a pace of noise reduction that is unrealistic from the industry perspective, and reiterating that, without complaints relating to the types of aircraft DJI is developing, the regulatory approach “seems indeed to be a solution in search of a problem.”

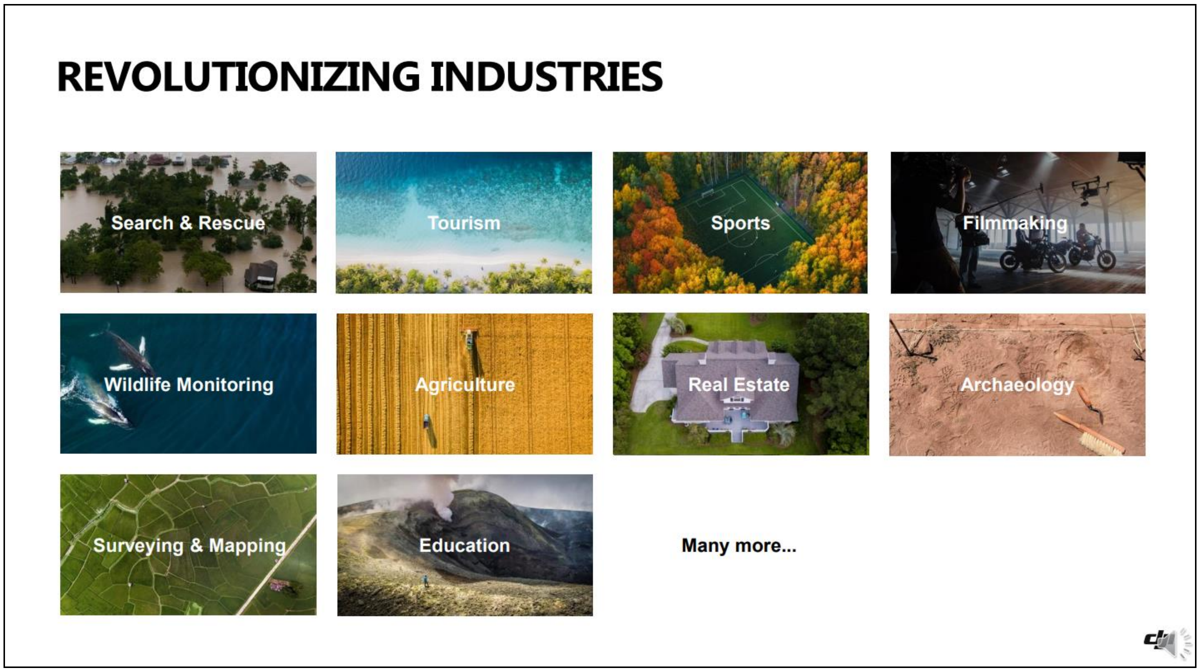


Figure 26-1 *DJI develops technologies across a broad range of industries*

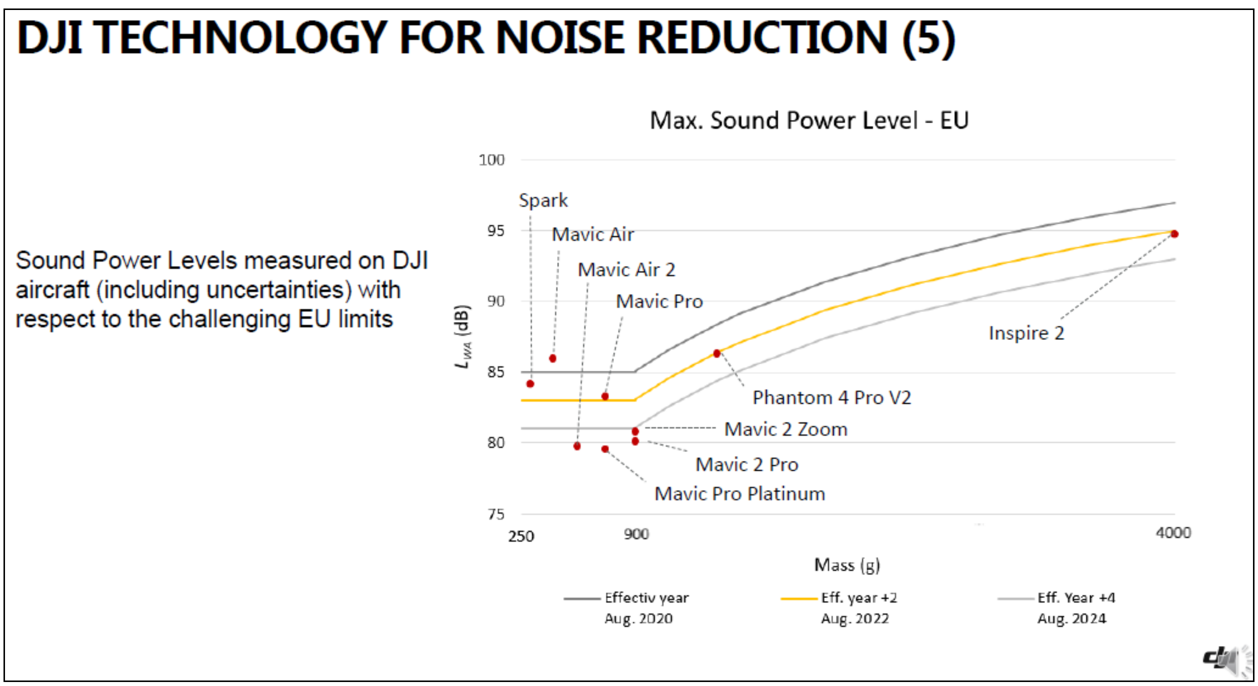


Figure 26-2 *Sound power levels for DJI aircraft compared to the EU 2019/945 limits*

EUROPEAN REGULATION (1)

- Commission Delegated Regulation (EU) 2019/945 as amended by (EU) 2020/1058 defines maximum Sound Power Level for Open Category and its *entry into force* date was **August 9, 2020**
- EU moved forward with these regulations at the last minute in its process and without any indication of an actual problem. Although being proactive it was perhaps **overly cautious**, as generally we do not believe the noise of a small UAS has caused complaints anywhere in the world
- Very little time to consider the future path of products and to set the **aspirational limits of the future**, which were entirely **arbitrary**

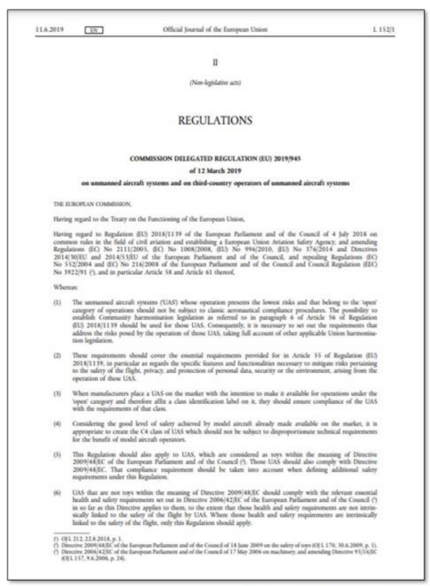
UA Class	MTOM (g)	Maximum Sound Power Level L_{WA} (dB)		
		As from entry into force	As from 2 years from entry into force	As for 4 years into entry into force
C1	$250 \leq m \leq 900$	85	83	81
C2	$900 \leq m \leq 4000$	$85 + 18.5 \log \frac{m}{900}$	$83 + 18.5 \log \frac{m}{900}$	$81 + 18.5 \log \frac{m}{900}$

Figure 26 -3 *European regulation: defining maximum sound power level for small UAS*

EUROPEAN REGULATION (2)

For C1, C2, C3 classes the manufacturer is required to determine the guaranteed **A-weighted sound power level** of the drone design

- UA shall be **hovering 0.5m** above a reflecting plane
- UA shall be completely enclosed in a **hemispherical**
- EN **ISO 3744:2010 Annex F** shall be applied
- **Three measurements** with max. deviation of 1dB
- Arithmetic means of the two highest values yield to the surface time-averaged sound pressure level L_{PA}
- Uncertainties due to production variation and measurement procedures are added
- Classes **C1 and C2 must stay below limits**, and C3 must indicate its sound power level only


REGULATIONS

COMMISSION DELEGATED REGULATION (EU) 2019/945

of 12 March 2019

on unmanned aircraft systems and on third-country operators of unmanned aircraft systems

Source: EUR-Lex (EU) 2019/945

Figure 26-4 Details of *European regulation on small UAS noise EU 2019/945*

REGULATORY AND STANDARDIZATION CHALLENGES (1)

Some findings from ASD-STAN Technical Report Noise group regarding EU 2019/945:

- UA maneuvering: sound level of hovering does not reflect the **noise during operations**
- Flying at **30-120m: sound power limits are lower** than for machines close to humans
- Test code **results are inconsistent** due to the shift of 0.5m above reflecting plane
- **Noise alerts humans** and is a **safety factor** itself – drones that are too quiet may undermine social acceptance and raise concerns about their ability to secretly "spy" on people
- **Noise limits are not diversified in operations** in urban environment at night, and inspection of industrial areas where machinery is running next to
- Indoor measurement using **ISO 3745:2010** shall be taken into account – this would avoid adding excessive and unnecessary measurement uncertainties
- **ISO 3744:2010 annex B and C** shall be acceptable as well

Figure 26-5 *A noise group's conclusions relating to EU 2019/945*

27. Legal Preemption and Aerial Mobility Noise Concerns

Robert Kirk—Wilkinson Barker Knauer, LLP

Aerial mobility noise is primarily controlled through federal regulation, given the doctrine of preemption, with state and local authorities left with little authority in this area. Private aerial mobility companies, meanwhile, are in a position to take important voluntary steps to respond to community concerns and up the odds of public acceptance of this potentially transformative industry.

Robert Kirk, a partner in the Washington, DC, law firm of Wilkinson Barker Knauer, shared his expertise gained from many years of practicing law with a focus on unmanned aircraft. With respect to aerial mobility, which Kirk described as "potentially transformative," noise has been identified as a possible barrier to widespread implementation, particularly with regard to larger aircraft. In his presentation, Kirk presented his perspective on legal aspects of aerial mobility noise issues, addressing topics such as preemption's relevance to regulation in this field and whether industry and state and local governments play any role.

The "FRISCO" approach provides a useful framework for analyzing noise issues, the presenter stated:

- *__F__ederal __R__egulation.* This is the primary means of addressing aerial mobility noise issues.
- *__I__ndustry __S__afeguards/Standards.* This refers to voluntary steps industry can take to recognize and address community concerns.
- *__C__ommunity __O__utreach.* This type of communication can help industry and government alike identify community concerns.

Federal regulation is the linchpin for regulating aerial mobility noise, and aircraft generally, because aircraft collisions in the 1950s prompted Congress to enact the Federal Aviation Act of 1958 establishing federal control over the airspace. (See Figure 27-1.) While the act itself has been essentially replaced over the years, the federal framework remains the same, Kirk said. The FAA has responsibility under federal law for the regulation of the flight and safety of "aircraft," which the speaker noted includes aerial mobility vehicles under the statutory definition. And noise is indivisible from the aircraft, the U.S. Supreme Court has concluded, saying that "to exclude the aircraft noise from the town is to exclude the aircraft."

The Noise Control Act of 1972 affirmed federal control over aircraft noise issues, with responsibilities assigned to the FAA and the Environmental Protection Agency. Congress directed the Secretary of Transportation to establish a national aviation policy through regulation. Under the doctrine of preemption—and field preemption, specifically—state and local regulation of noise associated with aerial mobility is impermissible. Preemption, Kirk explained, is a doctrine based on the Constitution's Supremacy Clause that makes U.S. laws the supreme law of the land, and gives Congress the power to preempt state law. The field preemption type occurs when a federal framework for regulation is so pervasive that Congress has left no room for state involvement.

Court cases, including those summarized in Figure 27-2, have shaped the application of preemption in the context of aircraft and aerial mobility. In *Burbank v. Lockheed Terminal Inc*., the Supreme Court determined that noise regulation impacts aircraft operations and therefore preemption applies. The court noted that the pervasive nature of federal regulation of aircraft noise also leads to the conclusion that preemption applies. Preemption is even applicable in the context of small drones, as found by a Massachusetts court.

The FAA addresses aircraft noise through stringent noise standards for new aircraft, Kirk said. He added that the agency also engages in noise research and community outreach toward developing appropriate standards.

The presenter next addressed industry standards and safeguards, as summarized in Figure 27-3. Companies can take a range of voluntary steps to address noise, he said, such as developing quieter aircraft, working with interested stakeholders to ensure that vertiports for takeoff and landing are located in areas that pose minimal noise concerns, and limiting flight times and number of operations in a geographic area.

About the final "FRISCO" element, community outreach, Kirk highlighted the importance of public acceptance for an industry's success. "There can be no debate," he stated, that "public concerns over noise can adversely impact public acceptance of aerial mobility operations." Obtaining community input on acceptable levels of noise can helpfully guide industry decisions such as those related to aircraft design and operations, Kirk said. Community outreach efforts should also include coordination with state and local governments, according to the speaker, which could reduce the likelihood of these actors attempting to enact airspace-related regulations, even as they are precluded from directly regulating aerial mobility laws.

Kirk next emphasized that the preemption doctrine does not prevent state and local governments from enacting requirements relating to any airports they own because governments are not acting in a traditional regulatory capacity as airport owners. Local jurisdictions are also permitted to incorporate airport noise compatibility planning as part of their local planning and zoning decision processes—thus, localities can try to indirectly address noise issues by, for example, locating vertiports and airports outside of areas most likely to cause noise concerns.

The speaker answered several questions following his presentation, making these main points:

- The line between noise regulation and land-use planning is a "gray area" that people could argue falls within preemption or outside of it based on the facts.
- Another gray area is whether local land-use planning is involved in routing and flight patterns—again raising the preemption question. While the FAA has the sole authority for regulating where one operates in the navigable airspace, certain restrictions can potentially be imposed by localities with respect to operations close to the ground or near a building.
- The trucking context, in which local noise ordinances can apply, is distinguishable from the urban air mobility realm, with operations solely within the FAA's authority according to the *Burbank* ruling.
- Constituents are continually talking with legislators about concerns with drones, with state and local authorities commonly trying to enact ordinances regulating where drones can operate. Noise from drone deliveries is likely to result in similar reaction.

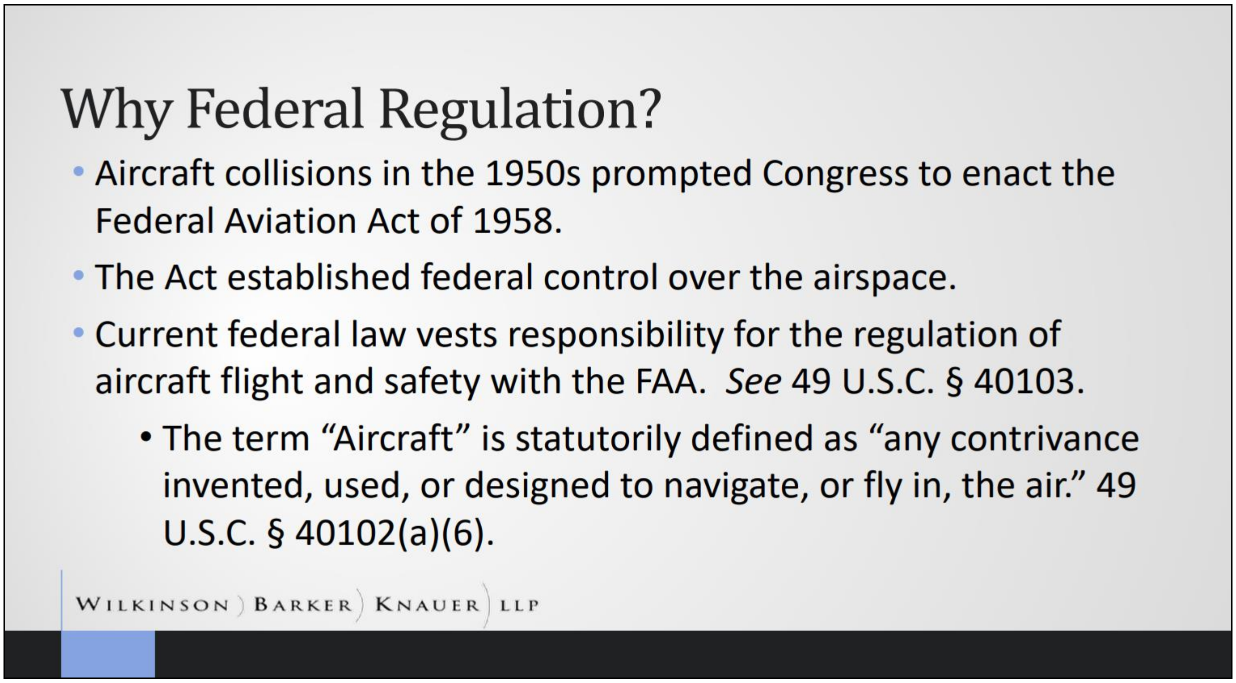


Figure 27-1 *Federal control's statutory underpinnings*

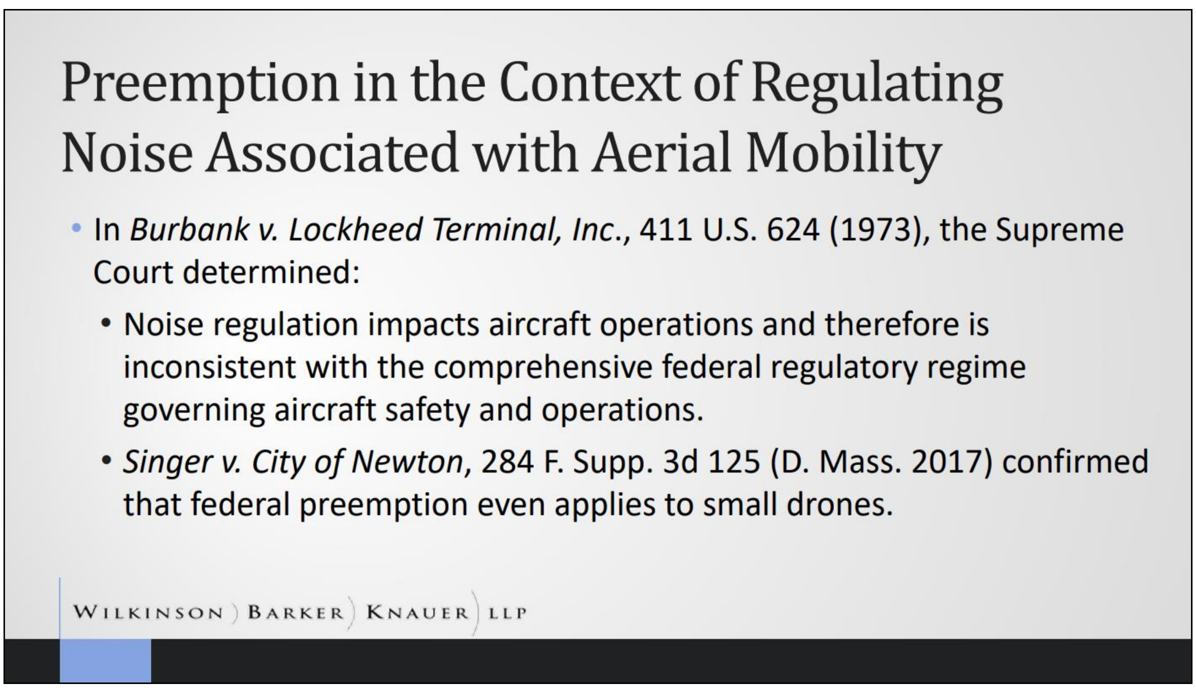


Figure 27-2 *Court cases establish preemption's broad applicability*

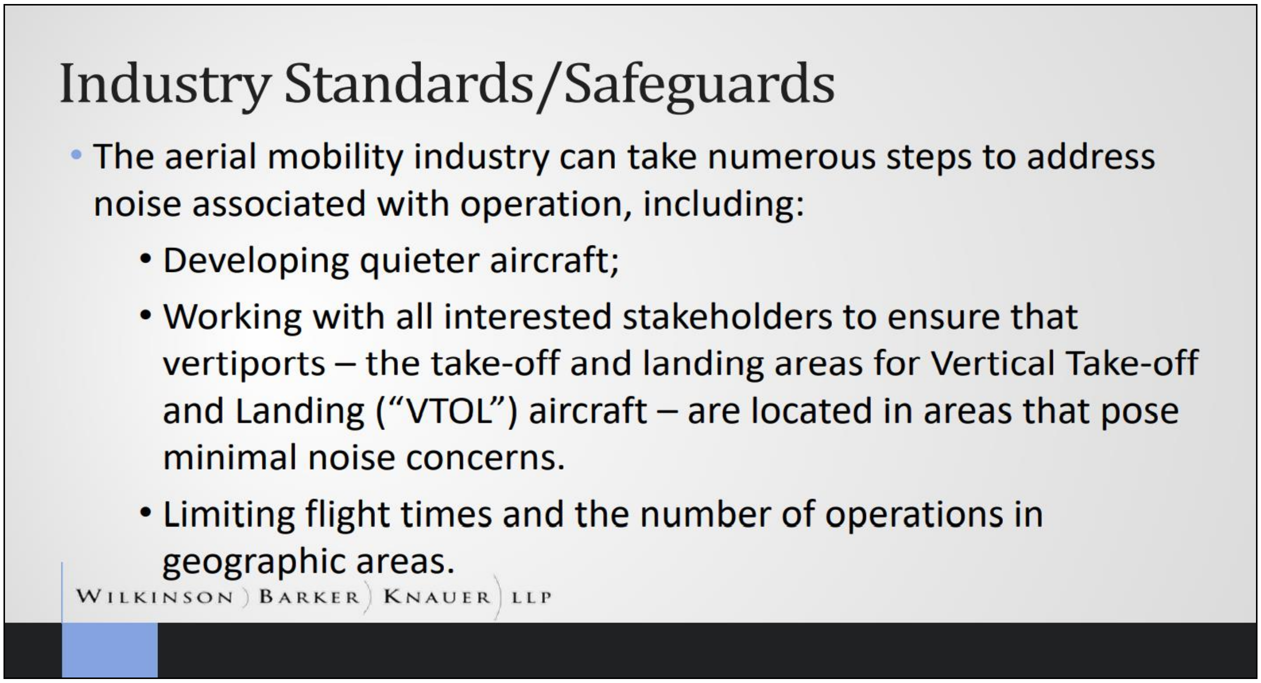


Figure 27-3 *Industry can take important steps to address aerial mobility noise*

28. Closing Remarks

George C. Maling Jr.—*NAE*

George Maling made a few remarks after the final paper in the final session in the workshop. James Hileman told us that airport noise has been around for a hundred years. The issue may have even started earlier than that, but in any case, Maling has been involved in some of the noise issues for about 65 of those years, and went through a few of the milestones as they relate to aviation noise. Someone mentioned the word warp speed. That seems to be a good expression to indicate that we must move on noise from aerial mobility vehicles sooner rather than later. He said that, "We don't have 65 years to solve this problem," so we must make progress quickly.

Maling has personal milestones with regard to aircraft noise. The first was in the mid-1950s. There was a magazine published by the Acoustical Society of America called NOISE CONTROL. One of the early papers in the issue questions whether the community response from aircraft noise could be quantified. The instrumentation in those days was very limited; for example, a sound level meter weighed about 20 pounds and then you needed an octave band analyzer, which was another 20 pounds. So, the measurement of noise around airports was difficult. But the article did quantify the noise in several categories, including threats of legal action.

Maling said that Andrew Christian mentioned another milestone and that was the problem when jet aircraft came in and the noise emissions were compared with that of conventional propeller-driven airplanes. Although the A-frequency weighted sound levels for both sources were about the same, the subjective reaction to jet aircraft was much more severe. The New York Port Authority commissioned Bolt Beranek and Newman to study the issue and produce a report. The upshot was that Karl Kryter and Karl Pearsons worked to define perceived noise level. At the time it took a van of equipment to make noise measurements on airplanes. For community noise exposure, we ended up with the day-night average sound level.

Another milestone was the 1978 paper by Theodore Schultz who quantified the relationship between DNL and community response. That was a major milestone, but the scatter in the data from various surveys was very large.

In about 1992, the Federal Interagency Committee on Aviation Noise (FICAN) produced a smooth curve through the data and adopted it for the purposes of public policy. It was a very successful outcome and the public is receiving major benefits today.

Then there is a problem, Maling said, that has arisen because of the availability of new navigation systems. Airplanes are now taking rather narrow and well-defined routes into airports, Logan Airport in Boston being a good example. Noise levels along the narrow flight path are now higher than before. Now the question is whether it is better to annoy a few people living under the flight path or to spread out the flight paths and subject a larger group of persons to lower but still increased levels of aircraft noise. That is a difficult question that so far does not have a good answer.

There is still the question of public acceptance. The public is much better organized and educated with respect to aircraft noise than in the "old days." Another concern with aerial mobility vehicles is that there are many more manufacturers today than there were with the development of commercial aircraft. During the workshop, Nicholas Lappos estimated that there are currently about 205 aerial mobility vehicles in development in 2020, and that perhaps 20-50 will enter the marketplace. This means multiple manufacturers further complicating the issue for the FAA.

So, the work on aircraft and air mobility vehicle noise is by no means complete and requires a faster response than in the past. Maling hopes that two years from now we will have another workshop and there will be much more to report on community acceptance of noise from airplanes and aerial mobility vehicles.

Maling said that there was concern when we found out in June or July, that the Keck Center of the National Academies was going to be closed during our meeting dates. We were not sure what we should do, but Sherri Hunter, meetings coordinator for the NAE came in and helped us to understand how to run the Zoom meeting. It's been somewhat new also to the NAE, so this has been quite a learning experience. We think it's worked out very well and we hope others agree. Sherri has guided us throughout the workshop, and we thank her for that. There are several other NAE people behind the scenes that I want to thank because they made this meeting run very smoothly. The first one is Mario Velasquez. He has been running the meeting, putting up slides, and helping us a great deal. And, the others were Edgar Gamboa, who also helped behind the scenes, and Dempsey Price who did a lot of work in getting these slides organized and checking them out. So, we thank all of those NAE people who made the meeting a success.

Jean Tourret thanked George Maling and the TQA committee for having invited him to this workshop to give a short summary of the Quiet Drones symposium. He said “I want to congratulate the organizers for this excellent program and the speakers for the quality and diversity of the presentations, but also all those people behind the scene, which makes this workshop so efficient.”

Tourret said that there was, in fact, a form of complementarity and even some informal synergy between the current event and the Quiet Drones symposium. And he indicated that both events have contributed to increased communication between individuals and countries. And, that it will pave the way for noise regulations in the not too distant future, that will lead to the best acceptability and use of drones. "So thank you again.”

Thanks to the 40 or so persons that attended the workshop. Thanks also to the team that we have, the steering committee for this meeting. We spent many months getting it organized; we had one meeting every week to discuss the progress on the invitations to speakers. And, everybody worked to put this together. We are very grateful that we had the support to organize this meeting.

Robert Hellweg added that he was impressed by the quality of the presentations and the synergy of the overlapping many themes from paper to paper being shared worldwide, among technical people and non-technical people. Thank you, he said, for everyone, both the presenters and those that provided the discussion and the comments that we've received.

That brings us to the question then of what's next. We have a reservation at the National Academy of Engineering during October 2021. We're not sure what the topic will be for that meeting. (Update: A virtual TQA workshop hosted by the NAE titled “*New Technologies for Noise Control*" is scheduled for October 19-21, 2021—Ed.)

APPENDIX A WORKSHOP AGENDA

Engineering a Quieter America

Aerial Mobility: Noise Issues and Technology
A TQA Virtual Workshop
Organized by the INCE Foundation in cooperation with NASA and FAA
Hosted by the National Academy of Engineering
December 2-3, 2020

Program

Wednesday, December 2, 2020

10:00am	**Session 1.** **George Maling and Adnan Akay, Moderators**
	Opening remarks *George C. Maling Jr.*
	Welcome from the NAE *John Anderson, NAE President*
	Keynote address: Advancing Aerial Mobility: A National Blueprint *Nicholas Lappos, Lockheed Martin, Chair of The Committee on Enhancing Air Mobility*
	Keynote Address: A brief summary of Quiet Drones 2020 Paris e-Symposium with focus on presentations and discussions related to aerial mobility *Jean Tourret and Dick Bowdler, INCE/Europe, and Philippe Strauss, CidB*
11:00	BREAK
11:10	**Session 2.** **Gregg Fleming and Eric Wood, Moderators**

The Future of the Air Cargo Industry
Stephen Alterman, Cargo Airline Association

Summary of the UAM Noise Working Group White Paper
Stephen Rizzi, NASA

The NATO work on progress for propeller and rotor noise design
Philip Morris, Penn State

12:10pm BREAK AND LUNCH

1:10 **Session 3.**
Robert Hellweg and Gregg Fleming, Moderators

From Helicopters to Quiet e-Vtols - A Manufacturer's Perspective
Julien Caillet, Airbus (France)

First Principles and Noise Considerations for Novel Air Vehicle Design
Brian Yutko, Boeing

1:50 BREAK

2:00 **Session 4.**
Gregg Fleming George Maling, Moderators

UAM Fleet Noise Assessments using the FAA Aviation Environmental Design Tool
Stephen Rizzi, NASA

Reducing community noise from delivery drones through route optimization
Eddie Duncan and Kenneth Kaliski, RSG, Inc.

Why is predicting audibility so hard?
Andrew Christian, NASA

3:00 BREAK

3.10 **Session 5.**
Eric Wood and Gregg Fleming, Moderators

Research considerations for aerial mobility and the role of noise certification
David Read, Volpe National Transportation Systems Center

Air mobility operational noise: perception and other community considerations
Judy Rochat, Herb Singleton, and Keith Yoerg, Cross-Spectrum Acoustics

4.00 Close First Day

Thursday, December 3, 2020

10:00am	**Session 6.** **George Maling and Adnan Akay, Moderators** Opening remarks Urban mobility Noise: Psychology of air vehicle noise *Alton D. Romig, Jr., NAE Executive Officer* FAA Perspective on Aerial Mobility *James Hileman, FAA* Overview of Future Noise Certification Needs for Aerial Mobility Aircraft *Donald Scata, FAA*
11:00	BREAK
11:10	**Session 7.** **Adnan Akay and Robert Hellweg, Moderators** Community response to UAS noise in the Virginia IPP *Mark Blanks, Mid-Atlantic Aviation Partnership* Framework for translating noise considerations into acceptable zones for vehicle operations and routing *John-Paul Clarke. University of Texas* Sound quality and its potential influence on the acceptability of aerial mobility noise *Patricia Davies, Purdue University*
12:10	BREAK AND LUNCH
1:10	**Session 8.** **Eric Wood and Gregg Fleming, Moderators** What is a sufficient noise metric? *Andrew Christian, NASA* Advanced Air Mobility: Facilitating Community Acceptance *Mary Ellen Eagan, HMMH* Small UAS Noise- Policy and Technology Considerations *Javier Caina, DJI*
2:10	Break

2:20	**Session 9.** **Robert Hellweg and Eric Wood, Moderators**
	Recent work of ANSI S12 WG58 on Small UAV Sound Measurement *Kevin Herreman, Owens Corning*
	Legal Preemption and Aerial Mobility Noise Concerns *Robert Kirk, Wilkinson Barker Knauer, LLP*
3:00	**Closing Session**
	Discussion *Workshop participants The Workshop Steering Committee*
	Closing Remarks

APPENDIX B   WORKSHOP ATTENDANCE LIST

Aerial Mobility: Noise Issues and Technology

December 2-3, 2020

Adnan Akay
Provost
Bilkent University

Nathan Alexander
Virginia Tech

Stephen Alterman
President
Cargo Airline Association

Koffi Amefia
MITRE

John Anderson
President
National Academy of Engineering

Sandeep Badrinath
PhD student
MIT

Ryan Biziorek
Associate
ARup

Mark Blanks
Director
Virginia Tech Mid-Atlantic Aviation Partnership

Dick Bowdler
Director
INCE Europe

Kenneth Brentner
Professor of Aerospace Engineering
Penn State University

Julien Caillet
Acoustic Expert
Airbus Helicopters

Javier Caina
Director of Technical Standards
DJI

Andrew Christian
Aerospace Technologist
NASA Langley

Charlotte Clark
Ove Arup and Partners

John-Paul Clarke
Ernest Cockrell Jr Memorial Chair in Engineering
University of Texas at Austin

Adam Cohen
Senior Research Manager
UC Berkeley

Bruce Conze
Moise Certification Specialist
US DOT FAA

Jeffrey Covert
Aviation Specialist
Environmental Science Associates

Daniel Cuppoletti
Assistant Professor
University of Cincinnati

Christopher Cutler
Physical Scientist
US DOT - Volpe Center

Patricia Davies
Professor
Ray W. Herrick Labs., Purdue University

Michael Doty
Aeroacoustics Branch Head
NASA Langley Research Center

Eddie Duncan
Director
RSG

Mary Ellen Eagan
President
HMMH

Gordon Ebbitt
Principal
Ebbitt Acoustical Consulting, LLC

Chrishanth Fernando
Principal
Hovecon Consulting

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

Daniel Friedenzohn
Embry-Riddle Aeronautical University

Emir Ganic
Research Associate
University of Belgrade

Christine Gerencher
Senior Program Officer - Aviation & Environment
Transportation Research Board

Chris Glancy
Research Portfolio Manager
Texas DOT

Rohit Goyal
Strategy Lead
Uber

Eric Greenwood
Assistant Professor
The Pennsylvania State University

Hua He
Engineer
FAA

Robert Hellweg
Hellweg Acoustics

Kevin Herreman
Principal Acoustic Scientist
Owens Corning

James Hileman
Chief Scientific and Technical Advisor for
Environment & Energy
FAA

Christopher Hobbs
FAA

Michael James
Chief Engineer
Blue Ridge Research and Consulting, LLC

David Josephson
Josephson Engineering, Inc

Kenneth Kaliski
Senior Director
RSG

Robert Kirk
Partner
Wilkinson Barker Knauer, LLP

Gary Koopmann
Senior Fellow
KCF Technologies

Robert Lang
Senior engineer
IBM

Nicholas Lappos
Senior Fellow
Lockheed Martin

Gina Lee-Glauser
President
Lee Glauser Associates, LLC.

George Maling
INCE Foundation

Jeffrey Mendoza
Technical Fellow, Acoustics
Raytheon Technologies Research Center

Frank Mobley
Research Physicist
United States Air Force Research Laboratory

John Morrison
Affiliation TBD

Tamar Nordenberg
Writer-Editor
Vie Communications

Melinda Pagliarello
Senior Director, Environmental Affairs
Airports Council International - North America

David Read
Lead, Aircraft Noise Certification Support
USDOT Volpe Center

Stephen Rizzi
Senior Technologist for Aeroacoustics
NASA Langley Research Center

Judy Rochat
Cross-Spectrum Acoustics

Alton Romig
Executive Officer
National Academy of Engineering

Donald Scata Jr.
Manager
FAA / AEE-100

Noah Schiller
Senior Research Engineer
NASA

Jared Schmal
Graduate Student
University of Kentucky

Roger Schmidt
Distinguished Prof.
Syracuse University

Kyle Schwartz
Senior Research Engineer
AVEC inc.

Natalia Sizov
FAA

Philip Soucacos
Deloitte

James Stephenson
US Army

Austin Thai
Graduate Student
Boston University

James Thompson
President
JKT Enterprises

Jean Tourret
President
INCE/Europe

John Varian
Aviation Environmental Specialist
Booz Allen Hamilton

Eric Wood
Consultant
Acentech

Amber Woodburn McNair
Assistant Professor
Ohio State University

Brian Yutko
CTO
The Boeing Company

NAE STAFF SUPPORT

Edgar Gamboa, Sherri Hunter, Dempsey Price and Mario Velasquez

APPENDIX C ACRONYMS AND DEFINITIONS

AAM	Advanced air mobility (or advanced aerial mobility)
AARON	ANOPP2 Aeroacoustic Rotor NOise tool in ANOPP2 (NASA)
ADS-B	Automatic Dependent Surveillance-Broadcast (FAA)
AEDT	Aviation Environmental Design Tool (FAA)
AEE	Office of Environment and Energy (FAA)
AF	Auditory filterbank
AFRL	Air Force Research Laboratory
AM	Aerial mobility
ANIMA	Aviation Noise Impact Management through Novel Approaches (EU)
ANOPP2	Aircraft NOise Prediction Program - second generation (NASA)
ANP	Aircraft Noise and Performance
ANSI	American National Standards Institute
ASA	Acoustical Society of America
ASCENT	Center of Excellence for Alternative Jet Fuels and Environment (DOT)
AVT	Aviation Vehicle Technology (NATO)
BATMAN	Broadband and Tonal Models for Airfoil Noise
CAA	Cargo Airline Association
CAEP	Committee on Aviation Environmental Protection (ICAO)
COE	Center of Excellence (DOT)
CFR	US Code of Federal Regulations
Cumulative Noise metric	Arithmetic sum of EPNL values in dB measured at three FAA aircraft noise certification measurement points
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
DGAC	French Civil Aviation Authority
DG MOVE	Directorate-General for Mobility and Transport (EC)
DNL	Day Night Level (a sound level metric that has a 10 dB penalty for night noise)
DOT	US Department of Transportation
EC	European Commission
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)
ESC	Electronic speed control
eSSTOL	Electric super-short takeoff and landing
EU	European Union
eVTOL	Electric or hybrid electric VTOL
FAA	Federal Aviation Administration
FRISCO	Federal regulation, industrial safeguards/standards, and community outreach
GPU	Graphics processing unit
Hz	The unit of frequency

ICAO	International Civil Aviation Organization
ICBEN	International Commission on Biological Effects of Noise
IMU	Inertial measurement unit
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
IPP	Integration Pilot Program (FAA)
ISO	International Standards Organization
L50	Sound level exceeded 50% of the time in dB
L90	Sound level exceeded 90% of the time in dB
LDEN	Day night evening sound level in dB (used in European regulations)
Leq	Equivalent sound level in dB
Lmax	Maximum sound pressure level in dB
$L_A$max	Maximum A-weighted sound pressure level in dB(A)
MTOM	Maximum takeoff mass (EU)
MTOW	Maximum takeoff weight (ICAO)
NAE	National Academy of Engineering
NASA	National Aeronautics and Space Administration
NASEM	National Academies of Sciences, Engineering, and Medicine
NATO	North Atlantic Treaty Organization
NCEJ	Noise Control Engineering Journal
NEPA	National Environmental Protection Act
NHPA	National Historic Preservation Act
NNI	Noise/News International
NPD	Noise-Power-Distance
OEM	Original equipment manufacturer
PNL	Perceived noise level in dB
PNLT	Tone Corrected Perceived Noise Level in TPNdB
RTG	Research Task Group (NATO)
RVLT	Revolutionary Vertical Lift Technology (NASA)
SAE	Society of Automotive Engineers
SEL	Sound Exposure Level in dB
SLM	Sound level meter
SMR	Signal to masker ratio
SPL	Sound pressure level in dB
SST	Supersonic Transport
STOL	Short takeoff and landing
TQA	Technology for a Quieter America
TRB	Transportation Research Board
UA	Unmanned aircraft (EU)
UAM	Urban air mobility
UAS	Unmanned aerial systems or unmanned aircraft systems
UAV	Unmanned aerial vehicle
UAV-DACH	Unmanned Aviation Association
UNSW	University of New South Wales

UNWG	Urban Air Mobility Noise Working Group (NASA)
VTOL	Vertical takeoff and landing
WG	Working group

CSA

Hellweg Acoustics

Acentech Incorporated

Aerial Mobility: Noise Issues and Technology