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Summary of Independent Technical Reviews of the NASA Scoping Document for UAM Community Response Test Preparation

Stephen A. Rizzi and Aaron B. Vaughn, Langley Research Center, Hampton, VA

Ben Cox, Joseph Digerness, David Hiller, Vincent Jurdic, Ana Luisa Maldonado, Raj Patel, Viviam Reyes, Joy Stephens, and James Woodcock, Arup US, Inc., New York, NY

Juliet Page, Shane Lympany, Blaine Harker, and Micah Downing, Blue Ridge Research and Consulting, LLC., Asheville, NC

Brandon L. Robinette and Joseph J. Czech, Harris Miller Miller & Hanson, Inc., Burlington, MA

Andreea Erciulescu, David Cantor, Eric Jodts, and Hanna Popick, Westat, Rockville, MD

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Langley Research Center
Hampton, Virginia 23681-2199

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Background

In April 2025, NASA's Langley Research Center requested Analytical Mechanics Associates (AMA) of Hampton, Virginia, under its Research, Science, and Engineering Services (RSES) contract (80LARC22R0003) to conduct independent technical reviews of a NASA-generated document defining the scope of a possible future multiyear technical challenge for the NASA Aeronautics Research Mission Directorate (ARMD), Advanced Air Vehicle Program (AAVP), Revolutionary Vertical Lift Technology (RVLT) project. This document was intended to serve as the basis for a white paper and subsequent AAVP tollgate review with start of execution early in FY26. A successful tollgate review is required for proposed AAVP technical challenges to move from the formulation to execution phase.

As indicated in the subsequent Statement of Work (SOW), NASA was working on a multiyear plan to formulate a technical methodology, develop needed analytical tools, and generate necessary data to inform subsequent efforts by the FAA Office of Environment and Energy (AEE-100) to develop a nationally representative long-term dose-response relationship for larger emerging technology aircraft (ETA), i.e., urban air mobility (UAM) or air-taxis, vis-à-vis other aircraft noise. Such dose-response relationships are necessary to inform policy (e.g., land use and environmental) at the federal, state, and local levels, with consultations as needed.

The objective of the AMA task was to assemble up to three Independent Review Teams (IRTs) to provide technical reviews of the NASA-developed Scoping Document, provided in Appendix A, for preparation of an eventual UAM community response test(s). The test(s) itself was(were) envisioned for a time in the future when certificated UAM vehicles are flying commercial operations over populations for extended periods of time. The test(s) was(were) to be conducted in the U.S., but populations outside of the U.S. are also of interest. For planning purposes, NASA considered this to be starting in 2030, although there is much uncertainty associated with that timeframe.

Multiple reviews were sought to provide a range of perspectives. The Scoping Document contains three main categories of activities: one for dose-related activities, one for response-related activities, and one for other activities. Comprehensive reviews addressing all three categories of activities were to be conducted by each IRT.

Description of Work

In its Statement of Work to AMA, NASA requested the following:

1. The Contractor shall assemble up to three independent review teams (IRTs), each with sufficient subject matter expertise to address all three categories of the Scoping Document, engaging outside experts as needed.

2. The Contractor shall provide comprehensive, independent technical reviews (one per IRT) of the NASA Scoping Document. Each review shall –
    - 2.1. Identify activities that are either missing (not represented in the Scoping Document) or that are unnecessary and provide the associated rationale.
    - 2.2. Identify alternative approaches and/or activities to accomplish the same objectives identified in section 2 of the Scoping Document and provide the associated rationale.
    - 2.3. Identify a preferred approach from the intersection of activities associated with 2.1 and 2.2 and provide the associated rationale.
    - 2.4. For the preferred approach in 2.3, provide detailed descriptions of activities down to the lowest level practical including an assessment of the level of maturity and identification of technical risks for each.

2.5. Identify significant milestones and any key decision points (KDPs), each with a brief description, due date, and exit criteria, assuming a 3-yr total duration from start to finish. This timeframe would allow the test preparation work to be completed prior to the test(s) being executed.

2.6. Provide a notional Gannt chart showing key milestones and KDPs, tasks, start and end dates, and dependencies.

3. The Contractor shall provide each IRT with NASA-generated responses to questions raised by other IRTs so that each IRT has access to the same information. Due to the short duration of this TDN, NASA-generated responses should be shared with IRTs within 2 business days following their receipt.

4. The Contractor shall provide one detailed final report per IRT that addresses task 2 (by July 24, 2025), and each IRT shall individually (virtually) brief NASA at the completion of the task (by July 31, 2025).

Project Execution

Technical Direction Notice (TDN) RSES.C2.02.00675 was released on April 16, 2025, with a period of performance from May 1, 2025, to July 31, 2025. AMA selected three IRTs according to the following NASA criteria –

> Each IRT team shall be composed of subject matter experts having demonstrated experience with aircraft community noise and with conducting aircraft community response surveys at a regional or national level, either inside or outside of the United States. Familiarity with advanced air mobility vehicle operations and the noise generated is highly desirable.

Based on these criteria, AMA selected the following as its IRTs: i) Arup US, Inc., ii) Blue Ridge Research and Consulting, LLC (BRRC), and iii) the team of Harris Miller Miller & Hanson, Inc. (HMMH) and Westat. During the period of performance, NASA-generated responses to questions were issued on June 22, June 23, and July 14, 2025 (see Appendix B). The period of performance was subsequently extended to August 15, 2025, to allow time for NASA to review the final reports prior to each briefing. The three briefings occurred the week of August 11, 2025.

Postscript

Since this work was initiated, it became clear that there is insufficient funding in the proposed FY26 NASA budget to pursue a new technical challenge as this time. Subsequently, the RVLT Project management decided not to proceed with the generation of a white paper that incorporates the perspectives offered by the ITRs, but instead to archive the Scoping Document and the ITR reports such that the work can be pursued when and if adequate funding becomes available in the future. To that end, the final reports of Arup, BRRC, and HMMH/Westat are provided, in full, in Appendix C, D, and E, respectively.

Acknowledgments

The authors wish to acknowledge the contributions of the following persons who provided substantive input into the NASA Scoping Document: Matthew Boucher, Andrew Christian, Siddhartha Krishnamurthy, and Kevin Shepherd (Emeritus Langley Associate) of NASA's Langley Research Center, Durand Begault (retired) of NASA's Ames Research Center, and David Senzig, Rudramuni (Muni) Majjigi, and Hua (Bill) He of the FAA Office of Environment and Energy.

Appendix A NASA Scoping Document

Scoping Document

For

Urban Air Mobility Community Response Test Preparation

NASA Langley Research Center

April 16, 2025

Foreword

The purpose of this document is to provide the scope of a possible future technical challenge for the NASA Aeronautics Research Mission Directorate (ARMD), Advanced Air Vehicle Program (AAVP), Revolutionary Vertical Lift Technology (RVLT) Project. It is intended to serve as the basis for a white paper, to be prepared not later than September 30, 2025, which will provide greater detail and itself form the basis for an AAVP tollgate review in Q2, FY26.

Notice

This document is intended to serve as a mechanism to share preliminary information within NASA and with external stakeholders. The scope of the proposed activity is subject to change and nothing in this document, implied or otherwise, shall be taken as an obligation by NASA or any other U.S. government agency, to pursue this or any other subsequent activity, in whole or in part.

Table of Contents

1. Background

Historical community noise surveys set the precedent to consider community response to a particular noise source. While the initial Schultz curve in the 1970s used dose-response data from communities' responses to various transportation noise sources, subsequent studies have differentiated responses by noise sources. Recently, the Neighborhood Environmental Survey (NES)[1] study sought to update the Schultz curve[2] and focused on fixed-wing aircraft noise. International studies (Miedema and Oudshoorn, 2001[3]; WHO, 2018[4]) have likewise examined community response to individual transportation noise sources using dose-response relationships. As urban air mobility (UAM) vehicles present a new noise into communities, there is a need to understand the community response specific to UAM noise.

This effort has similarities and differences with the NASA Quesst mission that is preparing to gather data on community response to en-route supersonic noise. Lessons learned from planning and execution of the Quesst mission may be applicable to UAM community noise efforts. Both studies seek to develop a nationally-representative dose-response relationship applicable to a new or unfamiliar noise source. They both require estimation of dose levels and survey methods to measure human response. A few key differences for UAM community noise survey efforts are that i) the FAA, not NASA, will lead the community noise survey and ii) NASA will not build a demonstrator or any other aircraft for community tests.

The execution of UAM community noise survey(s)/test(s) is envisioned to occur when certificated UAM vehicles are flying commercial operations over populations for extended periods of time. The test(s) will be conducted in the U.S., but populations outside of the U.S. are also of interest. For planning purposes, NASA considers testing to start in 2030, although there is much uncertainty associated with that timeframe.

2. Objectives

Primary Objective – NASA is to formulate a technical methodology, develop needed analytical tools, and generate necessary data to inform subsequent efforts by FAA Office of Environment and Energy (AEE-100) to conduct community noise survey(s)/test(s) and develop a nationally-representative long-term dose-response relationship for larger emerging technology aircraft (ETA), i.e., UAM or air-taxis, vis-à-vis other aircraft noise. Such dose-response relationships are necessary to inform policy (e.g., land use and environmental) at the federal, state, and local levels.

Given the desire for comparability with other (existing) aircraft noise, an NES-like study is envisioned with the dose measured by the day-night average sound level (DNL) and the response measured by the percent of the survey population as being highly-annoyed (%HA). Other measures of dose and response may also be investigated.

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[1] https://www.faa.gov/regulations_policies/policy_guidance/noise/survey

[2] Schultz, T. J. (1978). "Synthesis of social surveys on noise annoyance," J. Acoust. Soc. Am. 64(2), 377–405. https://doi.org/10.1121/1.382013

[3] Miedema, H. M. E. and Oudshoorn, C. G. M. (**2001**). "Annoyance from transportation noise relationships with exposure metrics DNL and DENL and their confidence intervals," Environmental Health Perspectives, 109(4), 409–416. https://doi.org/10.1289/ehp.01109409

[4] World Health Organization (**2018**). "Environmental noise guidelines for the European Region," World Health Organization, Regional Office for Europe, Copenhagen, Denmark. https://iris.who.int/handle/10665/279952

Secondary Objective – NASA is to investigate the relative contribution of sUAS as they relate to the ETA community noise environment.

A secondary objective is included here because it may not be possible, or even meaningful, to establish a dose-response relationship for UAM without also considering the contribution of small unmanned aerial systems (sUAS) for two main reasons: i) the two aircraft types may operate in the same environment and ii) the public may not discriminate between the two aircraft types when completing noise surveys.

3. Scope

As part of the proposed effort, NASA will undertake the activities outlined in sections 4 (dose-related activities), 5 (response-related activities), and 6 (other activities) of this document.

NASA activities will not include:

- Execution of the UAM community response test(s) itself, apart from possible early opportunities to evaluate activities outlined in sections 4, 5, and 6.
  - Development of the nationally-representative does-response curve will occur after the test execution and will also fall out-of-scope of the NASA-led activities outlined in this document.
- Development of regulation and/or policy based on the proposed work content.
- Noise certification-related efforts.
- Development or use of purpose-built aircraft.

4. Dose-Related

This main body of work focuses on efforts related to quantifying/estimating the noise dose/exposure. It includes predictive analyses, noise monitoring, and metrics.

A. Analyses

This main area is intended to focus on predictive analyses to quantify/estimate the noise dose. It includes computational tools for doing so, the data required to support those analyses, and consideration of the ambient noise in the operational environment(s).

i. Tools

This subtopic focuses on tools and tool development needed to estimate noise dose. At this time, it is not known what methodology will be used. Note that the NES used the FAA Integrated Noise Model (INM), predecessor to the Aviation Environmental Design Tool (AEDT)[5], to estimate noise dose. Since the noise dose estimates are not of the type mandated by FAA Order 1050.1F[6] for compliance with the National Environmental Policy Act (NEPA)[7], it may be that any methodology that can withstand scrutiny could be used. We also assume that outdoor noise dose estimates are to be made, and not indoor ones.

[5] https://aedt.faa.gov/
[6] https://www.faa.gov/regulations_policies/orders_notices/index.cfm/go/document.current/documentnumber/1050.1
[7] https://www.epa.gov/nepa/what-national-environmental-policy-act

a. Readiness of Modeling Approaches

The readiness and deficiencies of U.S. community noise modeling tools including integrated noise modeling tools (e.g., AEDT), simulation tools (e.g., NASA ANOPP2 Mission Analysis Tool[8], Volpe Advanced Acoustic Model[9]), and other simplified methods, will be assessed. The focus should be on modeling of UAM noise, but consideration of sUAS should be included given the secondary objective. It may be that a combination of tools is required. Likely some basis for method down selection is needed in this activity.

b. Tool Development

Some additional tool development is anticipated for modeling outdoor noise dose in urban environments. Note also that there is no recommended method, e.g., ICAO Doc 9911,[10] for computing noise dose of rotary wing vehicles (helicopter or UAM) using either integrated noise modeling or simulation approaches, see Section 6.B.

c. Tool Validation

Tool validation is needed to establish confidence in the noise dose estimates they produce. The validation will likely rely on acoustic flight test data.

ii. Data

This subtopic focuses on the data needed as input to the prediction tools for estimating noise dose. The data come in different forms for different tools but are mostly derived from acoustic flight test measurements according to current practice. A relevant question here is to what extent will prediction-based data be acceptable in lieu of measurement-based data.

a. Noise-Power-Distance (NPD) Data

NPD data are used in integrated noise modeling analyses and are derived from measured data. Large amounts of NPD data may be required to estimate the noise dose for some operations of interest, e.g., landing in which the vehicle transitions through many operating conditions from forward to vertical flight. In such cases, it would be impractical for manufacturers to provide all the data needed. The viability of augmenting measured NPD data with either predicted NPD data (using validated tools) or with NPD data from surrogate aircraft needs to be addressed.

b. Source-Noise Hemispheres

Source-noise hemispheres are used as input to simulation analyses. The data requirements for simulation using source-noise hemispheres are even greater than NPD data. A similar argument exists for augmenting measured hemisphere data with either predicted or surrogate aircraft hemisphere data. Other factors, such as the frequency range and spatial resolution of those data, need to be addressed.

[8] Lopes, L.V. and Burley, C.L., "ANOPP2 User's Manual: Version 1.2," NASA TM-2016-219342, 2016.
[9] "Advanced Acoustic Model (AAM) software," U.S. DOT Volpe Center, https://www.volpe.dot.gov/AAM, 2021.
[10] "Doc 9911, Recommended method for computing noise contours around airports, 2nd Edition," International Civil Aviation Organization, Montreal, Canada, 2018.

c. Data Requirements

The range of operating conditions for noise certification are minimal (still TBD, but e.g., max weight, best rate of climb, single cruise speed, etc.). There is a need for additional noise data that correspond to everyday operating conditions.

> What is the error introduced in noise dose estimates by using a limited set of available noise data? How is it best to characterize that error, e.g., change in contour area with a change in the amount of data used.

Operations data including routes and trajectories (nominal and off-nominal), aircraft operational conditions, cadences, etc., are needed for noise dose estimation. The NES noise estimates were based on aircraft flight data, including aircraft state, weight, configuration, other state data, and flight tracks. Twelve-month sets of data were used to account for seasonal variation. What constitutes the set of operations data needed for estimating UAM noise dose?

iii. Ambient Characterization

Unlike large fixed-wing aircraft operating in and out of airports, UAM will operate in areas where they may not be the dominant source. Hence, some characterization of the ambient noise is likely needed, whether that be to assess audibility, the effects of ambient on measured annoyance, or for survey siting. Characterization of the ambient is also needed to aid in signal processing for, and placement of, noise monitoring equipment (see Section 4.B).

a. Assess suitability of existing ambient noise models, e.g., Blue Ridge Research and Consulting AMBIENT model[11], National Park Service, or similar models, and measured data.
b. What is the variability of the ambient over time (hours, week/weekend, seasonal)? How does that affect data acquisition requirements if noise monitoring is needed.

B. Noise Monitoring

Analysis tools rely on data acquired from acoustic flight tests performed under ideal low-ambient conditions. This activity assumes that community tests will include some noise monitoring to compare dose measurements with the dose estimated by the analysis tools. An evaluation of that assumption is needed as well as consideration of the below.

i. Requirements Definition

Assess need and type of measurements in community tests, auxiliary data (e.g., weather), aircraft location, speed, and other (e.g., weight, flight condition)

ii. System Evaluation and Development

Evaluate existing special-purpose and COTS noise monitoring systems, cost vs. complexity, durability, ruggedness, connectivity, resistance to tampering, expected duration without human intervention. Develop or modify to meet requirements.

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[11] Rizzi, S.A., Christian, A.W., Letica, S.J., and Lympany, S.V., "Annoyance model assessments of urban air mobility operations," 30th AIAA/CEAS Aeroacoustics Conference, AIAA-2024-3014, Rome, Italy, 2024, https://doi.org/10.2514/6.2024-3014.

iii. Signal Processing

Develop signal processing methodologies to address how to measure signals in a high ambient environment, how the requirements change with the type of signal (e.g., measuring acoustic pressure time history versus SPL), use of multichannel systems and processing for time of arrival/beamforming-based algorithms, value of using ADS-B based tracking.

iv. Placement

Develop placement strategy including consideration of local environment constraints, sensor density, expected signal to ambient noise ratio, difference in required proximity to aircraft between sUAS and UAM classes, privacy concerns if placed on private or public property, and deployment method (e.g., poles versus ground plates).

C. Metrics

The dose will minimally be expressed in terms of DNL to compare with dose-response relationships established for other transportation noise sources. If metrics other than DNL are to be additionally considered, the eventual test(s) need to be constructed in such a way that allows that.

i. Consideration of Duration and Number of Events

a. A 24-hour dose does not account for the variability of ambient levels as a function of the time of day; e.g., commute hours have higher ambient levels than mid-day (school, work) hours. This may be more important for UAM than large commercial transports.

b. Is there a breakdown of applicability for any identified dose metric if the number of events is low, high, or changes?

c. Is the community noise dose in a steady state? Is it still possible to conduct a cross-sectional type study (see Section 5.B) if the number of operations are changing over time scales of interest?

ii. Considerations for Other Metrics

a. What is the purpose of a different metric, e.g., is it being considered as an "alternative" metric (uncorrelated with DNL and that improves prediction of noise impact, Fidell et al.[12]) or as a "supplemental" metric (may be correlated with DNL but improves communication with public).

b. What are data requirements and/or tools to support use of any other metric considered?

5. <u>Response-Related</u>

This main body of work covers efforts related to quantifying the community response. It includes analysis methods and tools, survey methods, and metrics.

[12] Sanford Fidell, Vincent Mestre, Paul Schomer, Bernard Berry, Truls Gjestland, Michel Vallet, Timothy Reid; "A first-principles model for estimating the prevalence of annoyance with aircraft noise exposure," J. Acoust. Soc. Am. 1 August 2011; 130 (2): 791–806. https://doi.org/10.1121/1.3605673

A. Analysis Methods and Tools

Assessment of analysis methods and tools are minimally required to support the following considerations –

i. Differences Across UAM Configurations

Responses may vary across UAM aircraft configurations, e.g., tiltrotors versus lift-plus-cruise. By what means may it be possible to generalize these responses in a way that allows a simple representation of the human response to a UAM vehicle?

ii. Statistical Dose-Response Modeling Methods

Provide a framework to create a dose-response relationship after data are collected. Models used in the NES and X-59 (e.g., multilevel logistic regression) may be applicable to UAM noise in addition to other models.

iii. Metanalysis Methods

The ACRP report[13] that preceded the NES indicated that individual studies often report contradictory findings necessitating need to average results across many studies. Metanalysis allows for leveraging research efforts from others to create a broader understanding of human response to UAM noise.

What methods/techniques may be used to combine results from different surveys to determine trends/relationships? How should surveys be constructed to facilitate metanalyses (see Section 5.B)?

B. Survey Methods

Survey methods encompass statistical methodologies to collect human response data in a community noise study. The study type determines whether a single or multiple surveys are conducted. The survey mode is how the response data are to be collected and the survey questions determine what response data are to be collected. Sampling covers who and where data are collected and influences how they are to be combined.

i. Study Type

A cross-sectional study refers to a single survey of a population at a snapshot in time, whereas a longitudinal (or panel) study involves multiple surveys of the same population over time. The NES was a cross-sectional study that surveyed multiple (20) populations.

Determine the time period over which response should be evaluated. What constitutes a long-term cumulative dose-response for UAM noise? How long does it take for the response to become steady state?

[13] National Academies of Sciences, Engineering, and Medicine (**2014**). “Research Methods for Understanding Aircraft Noise Annoyances and Sleep Disturbance,” Washington, DC: The National Academies Press. https://doi.org/10.17226/22352

ii. Survey Mode

Phone, mail, in-person, web? – NES had 40% response rate by mail

iii. Survey Questions

Consider noise sensitivities (background or end-of-test survey), annoyance question using ICBEN[14] recommendation, other supplementary questions, specify intent of survey or more broad survey (like NES) to avoid bias?

iv. Sampling

Sampling refers to the statistical process of collecting data from a subset of the population to describe characteristics of the overall population. This area covers topics to consider in establishing a nationally-representative dose-response relationship, such as sample size, site selection, and how or whether to combine data from multiple noise sources and communities.

a. Sample Size Considerations

How many people should be surveyed in each community/study or across multiple communities/studies?

b. Site Selection and Eligibility Criteria Development

How to we correlate simultaneous noise measurements with survey results (e.g., extrapolate/repropagate measurement to surveyed observer location)?

Can remote psychoacoustic tests (i.e., VANGARD) help guide where community testing should occur?

c. Combining Data from Multiple Noise Sources and Communities

A single, national dose-response relationship may not be justified because it may not be possible to objectively predict deviations from the national average for local geographic areas.

There may be a need to separate dose-response relationships for different classes of aircraft because AAM/UAM aircraft may have more varied acoustic signatures than large commercial transport aircraft (see Section 5.A.i.)

C. Metrics

This area covers two main topics: human response metrics and human response tests. The purpose of human response metrics here is to understand and characterize human response to UAM noise. The baseline human response metric in community noise studies is annoyance in terms of percent highly annoyed. Additional human response metrics may be considered. Human response tests consist of laboratory and field tests and are opportunities to obtain data to inform future community tests. Laboratory tests measure the human response to noise in a controlled environment with

[14] Fields et al., "Standardized general-purpose noise reaction questions for community noise surveys: Research and a recommendation," Journal of Sound and Vibration, 242(4), 2001, https://doi.org/10.1006/jsvi.2000.3384

recorded or auralized sounds. Field tests present opportunities to test survey methods and collect dose-response data in a lived-in environment with real vehicle sounds.

i. Alternative Response Metrics

This area concerns other response metrics besides %HA including but not limited to audibility (detection & noticeability) and acceptability.

ii. Laboratory Studies

Lab studies in controlled environments are intended to help guide future community noise tests and help identify alternative metrics. Some planned laboratory studies at NASA include the following:

a. A test comparing annoyance to UAM with annoyance to helicopters. This is intended to inform if UAM community surveys can be performed in mixed operational environments vs an isolated UAM-only operational environments.

b. A test comparing annoyance to UAM with annoyance to small UAS. This is intended to inform if the responses may differ and if people distinguish between the two aircraft types. This will help inform the secondary objective of whether to test in a mixed UAM/sUAS environment.

c. A second "Noise and Number" test to further investigate the effect of the number of operations on annoyance to UAM.

d. A second test investigating the effect of ambient noise on UAM annoyance. This could help inform site selection.

e. Remotely administered tests like the "Varied Advanced air mobility Noise and Geographic Area Response Difference (VANGARD)" test to determine differences in annoyance response in different communities in the U.S. (and possibly later outside the U.S.)

In the above, how can auralization best be used to study human response when measured data of new entrants are either not available or the application is to support perception-influenced design of next generation vehicles?

iii. Early Field Test Opportunities

Assess tools and methodologies, survey methods, and metrics efficacy by leveraging early entry operations and demonstrations, including working with other research organizations (see Section 6) to study early operations outside of the U.S., e.g., UAE, and air taxi demos like those planned at the 2025 Osaka World Expo and the 2028 Los Angeles Olympics.

Study of early sUAS operations may also be helpful to understand human response to sUAS before commercial UAM operations begin.

6. <u>Other Activities</u>

This group of activities is a catch-all for those not directly related to dose and response. It includes, but is not limited to, coordination with various stakeholder groups, standards development, community engagement, and independent reviews.

A. Coordination

i. U.S. Government Agencies

FAA Office of Environment and Energy - The eventual survey(s) are to be FAA-led. Therefore, close coordination with the FAA Office of Environment and Energy is needed throughout the technical challenge. Further, there are some assets including the AEDT that are owned and managed by the FAA.

DOT Volpe Center - Has responsibility for development and maintenance of the AEDT and is likely a participant in the survey(s), especially oversight of dose estimation analyses and noise monitoring.

Federal Interagency Committee on Aviation Noise (FICAN)[15] – Forum for coordination with Department of Defense, Department of the Interior, Department of Transportation, Environmental Protection Agency, NASA, Depart of Housing and Urban Development.

ii. International Coordination

There is recognition that there will likely be similar survey activities directed at understanding human response to UAM operational noise that are conducted outside of the U.S. Further, it is not expected that NASA and/or the FAA will be directly involved in such activities. However, there is value in coordination/cooperation with organizations outside of the U.S. involved in those efforts from the standpoint of awareness (passive) and harmonization of surveys (active) to facilitate metanalyses across survey data.

Interaction with/through the following groups (and others) are envisioned –

a. International Civil Aviation Organization (ICAO), Committee on Aviation Environmental Protection (CAEP), Working Group 1 – noise and WG2 – Airports and Operations.

b. Other Regulatory Agencies, e.g., U.K. CAA, E.U. EASA, most of which already participate in ICAO/CAEP.

c. Other Research Organization, e.g., German DLR, French ONERA

d. U.S. and foreign OEMs conducting operations and/or demonstrations outside of the U.S.

B. Standards and Guidance Development

Engagement with standards making bodies to support tool/method development and data collection to support noise dose modeling, e.g., SAE A-21[16], or appropriate survey methods to the extent they might differ for this purpose, e.g., International Commission on Biological Effects of Noise (ICBEN).[17]

[15] https://www.faa.gov/fican
[16] Aircraft Noise Measurement Aviation Emission Modeling
[17] https://www.icben.org/

Engagement with the UAM Noise Working Group (UNWG) for generation of guidance documents, like the measurement protocol[18] developed by UNWG subgroup 2 on Ground and Flight Testing, or a survey protocol by UNWG subgroups 3 and 4.

C. Community Engagement

With the possible exception of early field test opportunities (Section 5.C.iii), actual community engagement is not a focus in the new technical challenge. Rather, the focus in the new technical challenge is to identify how and what community engagement should be performed leading up to and during eventual UAM community survey(s). A possible forum for engagement of this topic is through the NASA Advanced Air Mobility (AAM) Ecosystem Working Group on Community Integration.[19] Other engagement is likely at a local or regional level versus at a national level.

D. Technical Reviews

The RVLT technical challenge for UAM Community Response Preparation will be subject to review by the NASA Aeronautics Research Mission Directorate as part of the annual project reviews.

It may be that the technical challenge could also benefit from periodic independent reviews, as needed prior to survey(s).

[18] https://ntrs.nasa.gov/citations/20240011587
[19] https://nari.arc.nasa.gov/aam-portal/community

Appendix B Frequently Asked Questions

Frequently Asked Questions for TDN RSES.C2.02.00675

"Independent Technical Review of NASA Scoping Document for Urban Air Mobility Community Response Test Preparation"

6/22/2025

Q1: What is the preferred format for the final report (Deliverable 10.3)?

A1: The final report should be a standalone document with sections corresponding to the SOW 2.2.1-2.2.6. This standardized format will aid in evaluation of the final reports from the Independent Review Teams.

--

Q2: What is the preferred electronic format for the final report (Deliverable 10.3)?

A2: The SOW indicates all documents should be provided in Microsoft Office or PDF format. The NASA Technical Point of Contact prefers both Microsoft Word and PDF versions.

--

6/23/2025

Q3: Could you clarify how long communities are expected to have been exposed to this noise source by the time these surveys are conducted?

A3: Not entirely. It is safe to say that the operations should not be a novelty as would be the case for a series of demonstration flights over the course of a few weeks or months or for infrequent operations. A more reasonable timeframe is probably a year or more of continuous operations. NASA would like the thoughts of the independent review teams (IRTs) on this.

--

Q4: Regarding the primary objective, are there any reasons for the focus on long-term response?

A4: The FAA's Neighborhood Environmental Survey (NES) established a new long-term dose-response relationship for mostly large commercial transports operating out of airports. The findings were, in part, a reason for undertaking the FAA Noise Policy Review (currently underway). There is interest in determining how/if the dose-response relationship for UAM differs from the NES curve.

--

Q5: The primary objective suggests a lower limit in size, but not an upper limit (i.e., flying bus). Should there be an upper limit?

A5: This study intends to focus on prevalent eVTOL aircraft architectures that are currently on the path to aircraft type certification.

--

Q6: Regarding the secondary objective of investigating the contribution of sUAS, what is NASA's view on that?

A6: NASA is looking for the IRTs to chime in on this. Some worthwhile considerations might include conducting surveys in environments in which only sUAS or only UAM are operating versus mixed environments. Laboratory studies could also inform what perceptual differences between the two vehicle classes might be like.

--

Q7: Is this work limited to community response or should other health effects also be considered?

A7: This work is limited to community response, and that should minimally include annoyance. Health effects are out of scope.

--

Q8: AEDT and other integrated models are typically limited to Leq and Lmax type metrics. Will the study look at other psychoacoustics/sound quality metrics?

A8: Dose metrics should minimally include DNL. Response metrics should minimally include %HA. The extent to which other metrics for either dose or response should be considered is for the IRTs to chime in on.

--

Q9: Is the intention to continue developing AEDT to accommodate UAM and establish it as the global standard? Or will there be an effort to develop guidelines or frameworks allowing organizations to build and validate their own modelling tools independently?

A9: The recommended method (not a standard) for estimating noise exposure in the vicinity of airports is the ICAO Doc. 9911. This applies to fixed-wing aircraft only and does not include helicopter modeling. The AEDT follows Doc 9911 for fixed-wing aircraft, but also includes helicopter modeling. NASA has made recommendations to the FAA for improvements to the AEDT to better support UAM. Some of these are expected to appear in the next release (v4a). Alternative methods include simulation, for example, the Volpe Advanced Acoustic Model. Recommended methods for modeling UAM noise exposure would likely fall in the domain of the ICAO Modelling and Database Group (creator of Doc. 9911). However, there are no known plans for doing so currently. The gist of the comment in section 4.A.i regarding the method having to withstand scrutiny should be interpreted to mean that it is a de facto standard and in a code that is widely accessible (vs black box company proprietary).

--

Q10: Regarding the statement that some additional tool development is anticipated for modeling noise does in urban environments (4.A.i) - Given the correct source characterization, software such as Soundplan, can already do that. Although we understand that an optimized tool could be a better option, has this been considered?

A10: NASA has been primarily focused on simulation and integrated noise modeling tools, which do not have well developed capabilities for modeling sound propagation in urban environments. If Soundplan or any other commercial tool (referring to A9 here) is capable of doing so, then please address it.

--

Q11: Regarding the statement in 4.A.ii – What constitutes the set of operations data needed for estimating noise dose?

A11: This is to be addressed by the IRTs and may be dependent on the modeling approach.

--

Q12: Regarding the ambient characterization (4.A.iii), should the combined noise sources be considered?

A12: No, the ambient noise should be characterized in the absence of noise from UAM operations to address questions a. and b.

--

Q13: Regarding 4.C, over what period will the assumptions for Leq type metrics be defined? Annual average operations, peak day, average busy day, etc.?

A13: Given that the dose-response relationship is to be compared with the new curve established by the NES, the process should be the same or similar (see below excerpt). If other Leq type metrics are suggested, then please state the benefit of doing so.

From Section 7 "Computation of DNL for Average Daily Flight Operations" of the NES report –

> *Cumulative aircraft noise exposure is typically presented in terms of DNL that is based on annual average daily operations. Examining a year's worth of data accounts for seasonal or other variability in aircraft operations. For this project, a method was devised to compute noise exposure for every day of a year and the overall annual average day DNL in a consistent, repeatable manner for each airport considered.*

<u>7/14/2025</u>

Q14: Is the 3-year duration intended to be just the planning/prep stage or everything from planning through execution and analysis?

A14: The 3-year duration is intended to be just the planning/prep stage. Please also note that the scope of this proposed activity does not include execution and post-test analyses.

--

Q15: What are NASA's thoughts on the effort looking into non-acoustic factors for annoyance?

A15: To the extent that the IRT thinks looking into non-acoustic factors for annoyance is relevant to the effort, then please include that bearing in mind that is not the primary or secondary objective of the proposed effort.

Appendix C Arup Final Report

NASA/AMA

Independent Technical Review of NASA Scoping Document for Urban Air Mobility Community Response Test Preparation

Arup Report of Technical Review

Reference: R01

Issue | July 24, 2025

© Systems Analysis and Concepts Directorate, NASA Urban Air Mobility (UAM) Reference Vehicles

Job number 309715-00

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Arup US, Inc.
140 Broadway
New York, NY 10005
USA
arup.com

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		Name	Ana Luisa Maldonado Ben Cox James Woodcock Joy Stevens Viviam Reyes	David Hiller Joseph Digerness	Raj Patel
		Signature			

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1. Executive Summary

Arup performed an independent technical review of the NASA scoping document for the Urban Air Mobility (UAM) Community Response Test Preparation study in combination with current best practice, drawing on published literature and Arup's own project experience.

Our preferred approach includes a three-year lead-in period divided into four sequential phases (kick-off, development, pilot testing, and refinement) each with defined milestones and key decision points. The initial phase focuses on stakeholder engagement, requirement elicitation, and pilot testing site selection. The development phase involves building and validating noise modeling tools, designing the survey instrument, and establishing data governance protocols. A 12-month pilot study follows, testing the proposed methodology and tools in selected communities. The final phase refines the approach based on the findings of the pilot testing and prepares for handover to the FAA for the full study. This approach ensures that the methodology is robust, representative, and ready for full-scale deployment.

Dose-related activities focus on using an integrated model such as AEDT for large-scale noise exposure estimation, supported by model validation and calibration through noise monitoring. Where measured source data is unavailable, validated prediction methods are recommended. Sensitivity testing should compare AEDT with models that account for complex propagation effects in urban environments. L_{Aeq}-based metrics are recommended for primary analysis, with event-based and psychoacoustic metrics explored in subsets. The approach also emphasizes early stakeholder engagement, international coordination, and adherence to data protection principles to ensure scientific robustness and operational success.

For response-related activities, Arup recommends a postal survey with follow-up telephone interviews as the most pragmatic approach, balancing data quality and cost. Site selection should follow a balancing factor approach, with stratified sampling within noise exposure bands. The questionnaire should follow ISO/TS 15666 guidance, include both semantic and numerical annoyance scales, and be framed to avoid bias. It should address general and source-specific annoyance, time-of-day effects, and collect data on socio-demographic, attitudinal, and contextual factors. Dose–response modeling should use multilevel grouped regression to account for site and individual variability.

In addition to dose and response activities, the preferred approach includes a coordinated framework for project governance, stakeholder engagement, and standards development. Stakeholder mapping and requirements elicitation are initiated early, guided by ISO/IEC/IEEE 29148, and supported by structured validation and management processes. International coordination is recommended through ICAO Working Groups and regulatory agencies, with a dedicated technical working group proposed to harmonize survey methods and modeling approaches globally. Local engagement is prioritized to mitigate risks and ensure transparency, supported by a robust communication plan. Standards under development by bodies such as SAE and BSI are monitored to ensure alignment and interoperability. Data protection principles are embedded throughout, following best practices to safeguard privacy and build trust.

This review of the scoping document also identifies the following missing activities.

- In the dose-related section, the following gaps were identified:
  - Sensitivity testing to understand the level of complexity needed to represent specific scenarios and consequently, which modeling technique is needed to represent the physics in such a way that the model is complex enough to represent the real scenario but simple enough to be tackled in the required timescales with available hardware and software.
  - The use of IoT sensor networks for wide-scale noise monitoring.
- In the response-related section, the following gaps were identified:
  - The inclusion of source-specific annoyance questions, alongside the general annoyance questions.

- Questions on annoyance responses at different times of day.
- Reference to ISO/TS 15666, which contains the most up-to-date ICBEN guidance for the wording of response questions and scales.
- An activity to define sources, making sure the definitions are understandable by the public.
- Consideration of non-acoustic factors and data on activity disturbance, including self-reported sleep disturbance.
- Inclusion of open qualitative questions to provide context to the quantitative annoyance responses.
- Inclusion of any significant pilot testing component.
- Consideration for exploratory laboratory studies, to complement the laboratory studies proposed in the scoping document and to feed into the definition of sources.

* In the other activities section, the following gaps were identified:
  - A methodology for stakeholder mapping and requirements elicitation to be included from the first month of the project.
  - Coordination with local jurisdictions and the development of a communication and engagement plan to reduce risks.
  - Consideration of standards and guidance being developed outside the United States to promote the harmonization and transferability of methods and metrics for a meta-analysis.
  - Consideration of data protection principles is included as we understand this significantly minimizes risks.

2. Introduction

The National Aeronautics and Space Administration (NASA) is currently working on a multiyear plan to formulate a technical methodology, develop the required analytical tools, and generate the necessary data to inform subsequent efforts by the Federal Aviation Administration (FAA) Office of Environment and Energy to conduct community noise surveys with the aim of developing a nationally-representative long-term dose-response relationship for urban air mobility (UAM) vehicles. The community noise surveys are proposed to be observational studies in communities exposed long-term to UAM noise with a secondary objective to investigate the contribution of small unmanned aerial systems (sUAS) noise.

NASA has developed a technical scoping document[1] in preparation for the eventual community noise studies. The scoping document details key considerations relating to dose, response, and other activities (such as coordination with stakeholder groups). Arup has been engaged by NASA as one of three independent review teams (IRTs) to provide technical reviews of the scoping document.

The objectives of the IRT reviews are to:

1. Identify activities that are either missing (not represented in the scoping document) or that are unnecessary and provide the associated rationale.
2. Identify alternative approaches and/or activities to accomplish the same objectives identified in section 2 of the scoping document and provide the associated rationale.
3. Identify a preferred approach from the intersection of activities associated with (1) and (2) and provide the associated rationale.
4. For the preferred approach in (3), provide detailed descriptions of activities down to the lowest level practicable, including an assessment of the level of maturity and identification of technical risks for each.
5. Identify significant milestones and any key decision points (KDPs), each with a brief description, due date, and exit criteria, assuming a three-year total duration from start to finish. This timeframe would allow the test preparation work to be completed prior to the test(s) being executed. The three-year duration is intended to be for the planning stage and does not include execution and post-test analyses.
6. Provide a notional Gannt chart showing key milestones and KDPs, tasks, start and end dates, and dependencies.

This report presents the outcomes of Arup's review. To address objectives 1, 2 and 3, a comprehensive review of current best practice based on published literature and Arup's project experience has been carried out for each of the key topics identified in the scoping document. The review has been used to identify activities that are missing in the scoping document and to shape Arup's preferred approach. This review is detailed in sections 3, 4, and 5 for dose-related activities, response-related activities and other activities, respectively.

Section 6 identifies gaps and/or missing activities in the scoping document. A narrative detailing Arup's preferred approach to the study, along with descriptions of activities and the identification of potential risks, is provided in section 7. A detailed plan of execution for the three-year planning phase for the study, including key milestones and key decision points (KDPs) is presented in section 8. This addresses objectives 4, 5 and 6.

[1] NASA Langley Research Center (2025). Scoping Document for Urban Air Mobility Community Response Test Preparation. Version 4, April 16, 2025.

3. Dose-Related

3.1 Aims and objectives

To derive a dose-response relationship for UAM and sUAS noise, it is necessary to quantify noise exposure for each respondent to the community noise survey (see section 4 for response measurement activities). Dose-response relationships for transportation noise are typically derived using estimates of long-term average outdoor noise exposure[2]. Given the scale of locations for which estimates of noise exposure are required (likely in the 1,000s), it will not be practicable to obtain these estimates through measurement. Considering this, a modeling methodology capable of representing different UAM and sUAS vehicle types and operational modes is required.

Input data or simulation models will be required to provide source data for UAM and sUAS vehicles. While some data (e.g. Noise-Power-Distance (NPD) curves) could be provided by Original Equipment Manufacturer (OEMs), this data may not be readily available and may impose costs or burdens on stakeholders. As the questionnaire will likely assess annoyance over a 12-month period, operational data covering this timeframe will also be needed to allow modeling of long-term noise exposure patterns.

Unlike conventional aircraft, UAM and sUAS will operate at lower altitudes and within complex urban environments. Therefore, modeling may need to account for factors such as building screening, reflections from facades, diffraction around and over objects, and propagation over hard or mixed surfaces, elements typically excluded from conventional aircraft noise models. Given the complexity this introduces to the modeling approach, such effects may be better addressed through sensitivity analyses.

The modeling approach will need to support calculation of all relevant noise metrics used in the study. The primary exposure metric is most likely to be L_{Aeq}-based, the equivalent continuous sound level that represents the average acoustic energy over a specified period (i.e. L_{dn} the day-night average level, L_{den} the day-evening-night average level, $L_{Aeq,16hr}$ the 16-hour, A-weighted average, etc.). Event-based metrics such as L_{Amax} and metrics quantifying the number of events such as number-above (N_x) will also be needed. Consideration may also need to be given to sound quality and psychoacoustic metrics.

These considerations, along with Arup's preferred approach, are set out in the following subsections.

3.2 Analyses

3.2.1 Tools

Existing aviation modeling tools can broadly be split into two categories: tools based on measured data and tools based on mathematical predictions (called 'integrated' and 'simulation' tools in this report, respectively). Both categories have distinct capabilities and limitations, particularly in the context of UAM operations, that will drive the choice of tool(s) selected for the study.

3.2.1.1 Integrated tools

Integrated tools rely on measured aircraft noise data and model the noise exposure contours around airports due to airport operations. The measured data for each aircraft is typically in the form of NPD curves and the aircraft is treated as a single lumped directional noise source, with any deviations to the measurement conditions captured in various correction factors applied to the noise source. The NPD data are determined through fly-over measurements of individual aircraft types. These measurements can be expensive to perform, making it difficult

[2] World Health Organization (2018). The World Health Organization Guidelines for Environmental Noise Exposure for the European Region. World Health Organization Europe, Copenhagen: Denmark.

to have experimental datasets for all aircraft types, variants (airframe and engine combinations), and configurations.

Integrated tools tend to model aviation community noise using segmentation algorithms. These are considered the best practice for airport noise modeling by ECAC Doc 29 (4th Edition)[3] and ICAO Doc 9911[4]. In these models, the flight path is divided into linear segments where the aircraft's main performance parameters (such as aircraft thrust, velocity, flap modes, etc.) remain constant and therefore one NPD curve applies to each segment. From this, the noise contribution from each segment is estimated and summed at the receptors on the ground.

The reviewed integrated tools are outlined as follows:

AEDT

The Aviation Environmental Design Tool (AEDT) is developed and maintained by the Federal Aviation Administration (FAA) and is widely used in the US and the UK. It combines the assessment of noise, fuel consumption, and emissions from aircraft operations. The software is compliant with current international guidance on aviation noise modeling, including ECAC Doc 29 (4th Edition) and ICAO Doc 9911.

AEDT implements an integrated, segmentation-based calculation method to calculate noise and emissions from aircraft operations. The software includes a reference database containing approximately 4,600 aircraft (airframe/engine combinations) and approximately 400 non-aircraft emissions sources. This includes NPD acoustic data and a database of aircraft spectral classes, which are consistent with the Eurocontrol Aircraft Noise and Performance (ANP) database[5] (for fixed-wing aircraft). The NPD data represents the noise level for a given aircraft for different operational modes (i.e. departure / approach / overflight) and power settings. The data are provided for a range of slant distances from the aircraft to account for acoustic propagation through a standard atmosphere. It also includes standardized departure and arrival profiles for each aircraft (compliant with ANP and the EUROCONTROL Base of Aircraft Data[6] (BADA) 4 profiles), with the ability to create custom profiles to reflect local operations.

Noise can be calculated at individual receptors, over a grid of receptors, or as contours.

AEDT's calculation method includes corrections for duration, lateral attenuation (including ground effects), noise fraction, and atmospheric attenuation. Terrain effects, including terrain height and line-of-sight screening, are also taken into account in the calculation. However, the spatial scope of AEDT is national level, so terrain and line-of-sight analysis are based upon medium resolution datasets usually between 30 m – 90 m, like the USGS National Elevation Dataset. The software includes the option to disable the lateral attenuation correction for propellor aircraft and helicopters to simulate propagation over hard ground (e.g. concrete or water).

AEDT calculates a variety of exposure-based, such as L_{eq} and Effective Perceived Noise Level (EPNL) and event-based, such as L_{max} and N_x, metrics in different frequency weightings (A, C, and D-weighting). User-defined noise metrics, including time-of-day based penalty weightings, can be set up.

It is understood that version 4 of AEDT will include improvements to the helicopter prediction method, the modeling of mixed ground types, and handling of terrain and man-made structures.

[3] European Civil Aviation Conference. (2016). Report on standard method of computing noise contours around civil airports (4th ed.)

[4] International Civil Aviation Organization. (2018). Recommended method for computing noise contours around airports (Doc 9911, 2nd ed.)

[5] https://www.easa.europa.eu/en/domains/environment/policy-support-and-research/aircraft-noise-and-performance-anp-data

[6] EUROCONTROL (n.d.) Base of Aircraft Data (BADA). Available at: https://www.eurocontrol.int/model/bada (Accessed: 24 July 2025).

ANCON

ANCON (Aircraft Noise Contour Model) is the UK Civil Aviation Authority's modeling software used to produce annual noise contours for major airports in the UK in compliance with ECAC Doc 29 (4th Edition) and ICAO Doc 9911. Its inputs and calculation methodology are very similar to AEDT.

Its NPD acoustic database and flight profiles are checked and updated annually by taking several hundreds of thousands of noise measurements around Heathrow, Gatwick and Stansted airports, and therefore contains extensive noise information for the majority of aircraft types that operate from UK airports. It also includes the effects of terrain in the noise modeling process, although only for UK airports.

ANCON calculates exposure-based (L_{eq}) and event-based (L_{max}) metrics.

STAPES, IMPACT, and NORAH2

Similarly to AEDT, the SysTem for AirPort noise Exposure Studies (STAPES) is based on ECAC Doc 29 (4th Edition) and ICAO Doc 9911, and aircraft performance is also calculated using ANP and BADA 4 data, including helicopters and rotorcraft. STAPES is a research project, led by EUROCONTROL with European Union Aviation Safety Agency (EASA) and the Civil Aviation Authority in the UK (CAA) technical support to develop a noise model to assess the impact around airports, complying with current international guidance on aviation noise modeling (ECAC Doc 29 (4th Edition)[3] and ICAO Doc 9911[4]).

IMPACT calculates a variety of exposure-based (L_{eq}) metrics, although it is not clear from the documentation whether it can calculate event-based metrics. It is part of a suite of approved tools for assessment and modeling by ICAOs Committee on Aviation Environmental Protection (CAEP) and is the recommended tool for the European ATM Research Program.

STAPES has been integrated into the modeling platform IMPACT, which is an integrated aircraft noise and emissions modeling platform developed and maintained by EASA, the European Commission and EUROCONTROL, to estimate noise, fuel consumption, and gaseous emissions of aircraft. It uses a web-based application hosted and controlled by EUROCONTROL which does not require a powerful modeling computer on the user side.

STAPES includes an airport-specific database of aircraft flight profiles and NPD data, which covers a database of over 100 airports (mostly European) featuring information on runway and route layout, as well as the distribution of aircraft movements over these runways and routes. The calculation method includes ground effects, atmospheric effects, terrain effects, and weather effects. Aircraft performance is calculated using similar noise and emission data to AEDT, namely ANP and BADA 4 data.

The Noise of Rotorcraft Assessed by Hemisphere (NORAH) module is specifically dedicated to helicopter noise assessment where noise directivity might have significant impact (a similar approach to Advanced Acoustic Model (AAM), discussed in 3.2.1.2). The NORAH2 tool, including a software prototype and noise hemispheres database, was recently released following a four-year research project funded by the EU. It improves upon the original module and was created for rotorcraft noise assessments with future UAM operations in mind. It also includes propagation effects from buildings and topography.

RANE

Rapid Aviation Noise Evaluator (RANE)[7,8] was developed by the Institute of Sound and Vibration Research (ISVR) at the University of Southampton and employs a simpler modeling approach than AEDT and other

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[7] Torija, A. J., Self, R. H., & Flindell, I. H. (2017). A model for the rapid assessment of the impact of aviation noise near airports. The Journal of the Acoustical Society of America, 141(2), 981–995

[8] Amargianitakis, D. C., Self, R. H., Synodinos, A. P., Proença, A. R., & Torija Martinez, A. J. (2023). Closed-Form Analytical Approach for Calculating Noise Contours of Directive Aircraft Noise Sources. AIAA Journal, 61(4), 1735–1748

integrated noise modeling tools. NPD data is applied to each segment of the flight path to generate a 'noise cylinder' at a set noise level from the segment. The noise contours on the ground are then found from where the noise cylinder intersects with the ground.

ANIMA/SONDEO

Similar to IMPACT, ANIMA (Aviation Noise Impact Management through Novel Approaches) is a web-based tool coordinated by the French Office National d'Études et de Recherches Aérospatiales (ONERA) through the European Horizon 2020 project. ANIMA uses the Spanish SONDEO[9] model to predict noise levels and exposure.

Other modeling packages

Many countries have developed their own aircraft noise modeling methods. Most of them are based on the application of NPD curves at specific locations, corresponding to combinations of flight parameters, along a predefined flight path (FANOMOS[10] in Netherlands, IsoBella[11] in Ukraine, AcousticsLab in the Russian Federation, NOICE in Italy, ANCM in Spain, and the Japanese aircraft noise prediction method[12] to name a few).

Unfortunately, very limited technical information was available on these methods at the time of preparing this report, but they appear to use a very similar noise prediction method to AEDT.

3.2.1.2 Simulation tools

Simulation tools predict noise generation and propagation effects using physical models of the individual aircraft noise sources, including consideration of any installation effects that may alter the noise emission.

These tools take a different approach to the empirical models described in the previous section that are entirely dependent on the availability and reliability of experimental data. Empirical methods can vary in fidelity based on the number of independent variables evaluated in the model; this has an impact on the accuracy of the predictions and on the computational time required. Furthermore, the input parameters for empirical models are highly dependent on the availability of detailed design and performance data, which are typically very difficult to acquire at the time of measurement. Importantly, empirical models can only accurately represent existing noise sources.

An alternative to empirical models is simulation algorithms, where a combination of fundamental noise sources representing the aircraft are 'flown' along a discretized flight path. At each time step the aircraft performance variables are defined and a corresponding noise level is determined. A grid of noise receptors is located on the ground, and the source noise is propagated to each receptor for each time step, accounting for the propagation

[9] van Oosten, N. (2004). SONDEO: A new tool for airport noise assessment. INTER-NOISE and NOISE-CON Congress and Conference Proceedings, InterNoise04, Prague, Czech Republic, pp. 499–504. Available at: https://ince.publisher.ingentaconnect.com/contentone/ince/incecp/2004/00002004/00000008/art00074.

[10] Strümpfel, C. and Hübner, J., Aircraft noise modeling of departure flight events based on radar tracks and actual aircraft performance parameters. [online] Available at: https://www.researchgate.net/publication/340461180_Aircraft_Noise_Modeling_of_Departure_Flight_Events_based_on_Radar_Tracks_and_Actual_Aircraft_Performance_Parameters.

[11] Zaporozhets, O.I., Kartyshev, O.O. and Golembievskiy, G.G. (2008). Accuracy and uncertainty of aircraft noise modelling. Proceedings of the National Aviation University, 35(2), pp.52–57. Available at: https://www.jrnl.nau.edu.ua/index.php/visnik/article/view/1565 .

[12] Ministry of the Environment, Japan, n.d. Aircraft Noise Measurement and Evaluation Manual. [online] Available at: https://www.env.go.jp/air/noise/airplane/manual.html

attenuation through the atmosphere as per SAE-ARP-5534[13]. A time history of the noise level is therefore available for every grid-point receptor, and the overall noise level in the desired metric can be determined. While this approach can yield highly accurate predictions, it is often computationally demanding and requires highly detailed three-dimensional acoustic input data compared to the relatively simple segmentation algorithms typically used by integrated tools.

AAM

The Advanced Acoustic Model (AAM)[14] is the most recent aircraft noise prediction package, initially developed by NASA and managed by U.S. Department of Transportation (DoT) Volpe National Transportation Systems Center (Volpe Center). It can model helicopters, tiltrotor, and fixed-wing aircraft, and provide noise contours and sound simulation at a specific receiver.

Unlike AEDT, for example, AAM considers aircraft sound directivity by using three-dimensional noise sources, modeling the sound generated by aircraft at all angles and for different thrust vectors.

AAM models complex trajectory paths, including position, height, acceleration, airspeed, turn angle, vehicle orientation, and operating state. It can also model the effect of atmospheric conditions curving sound, although it currently only functions for wind and only on uniform, flat terrain for single event analysis.

The program includes a complex terrain modeling system and can calculate diffraction around simple barriers; this can extend to buildings, although the buildings themselves must be simplistic in shape. Ground reflection and wind refraction are considered, although it has been simplified to avoid problems with computation time.

AAM can predict many cumulative noise metrics (e.g. DNL, NEF, WECPNL) and single event metrics (e.g. N_x).

AAM allows for the modeling of multiple, simultaneous noise events or a series of separate events. This feature might be essential to assess the impact of future electric Vertical Take-Off and Landing (eVTOL) operations.

ANOPP2

The Aircraft Noise Prediction Program 2 (ANOPP2) is a varying fidelity noise model developed by NASA that combines several acoustic prediction approaches to undertake either low-computational cost modeling for design optimization or detailed, high-fidelity simulating models. It allows assessment of conventional and unconventional aircraft designs.

ANOPP2 can be used in conjunction with another NASA tool: Comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics II (CAMRAD II[15]), to create three-dimensional noise spheres for aircraft as a function of time throughout a flight event. These spheres can then be ‘flown’ through a simulation model to determine predicted NPD curves for the modeled aircraft, which can then be used in AEDT (with slight modifications) to calculate community noise exposure.

PANAM

The German Aerospace Centre (DLR) has developed tools to predict aircraft noise at a component level (TAU, PIANO) and an airport fleet level (PANAM). Noise predictions at the component level are derived using a combination of numerical and semi-empirical models, while the airport fleet predictions combine these individual component noise sources to construct comprehensive noise radiation profiles for flight configurations.

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[13] Society of Automotive Engineers. (2004). ARP-5534: Application of pure-tone atmospheric absorption losses to one-third octave-band level. SAE International.

[14] Wyle Report WR 16-08, Advanced Acoustic Model Technical Reference and User Manual

[15] Johnson, W. (1994). Technology drivers in the development of CAMRAD II. Presented at the American Helicopter Society Aeromechanics Specialists Conference, San Francisco, California, January 19–21, 1994. Available at: https://rotorcraft.arc.nasa.gov/Publications/files/Johnson_AHS94.pdf

Previously PANAM only predicted the airframe, fan, and jet noise from aircraft, but according to Domogalla (2025)[16], it has recently added the capability to predict propeller noise.

SonAIR

SonAIR is developed by Empa (Swiss Federal Laboratories for Materials Science and Technology) and is based on a single lumped noise source with three-dimensional directivity linked to the aircraft performance along a flight path (including thrust, velocity, flap settings, etc.). The source is 'flown' along a discretized flight path, for which historic flight radar data can be used to increase accuracy. Topography and ground reflections can be accounted for, as well as acoustic shielding from buildings. SonAIR can predict single event metrics (e.g. L_{ASmax}), cumulative noise metrics (e.g. L_{Aeq}), and psychoacoustic metrics (e.g. loudness or annoyance). Although this tool is often used to evaluate a single flyover event, its 'time step' approach can be annualized to predict airport noise exposure over time. From 2026, SonAIR will become the only officially recommended model for aircraft noise calculations in Switzerland.

3.2.1.3 Previous work on UAM community noise modeling

Over the last few years, NASA has assessed[17] [18] the capability of some of the tools mentioned above for UAM noise modeling. In particular, ANOPP2 has been used in conjunction with CAMRAD II (both NASA-developed methodologies) to derive NPD curves and source noise level data for two NASA UAM concept vehicles.

These NPD curves have been modeled in AEDT using both the fixed-wing and rotary-wing aircraft types, as well as hybrid approaches, where one is used for departure and approach operations and the other used for overflight operations. The fixed-wing method has advantages in that it allows modeling of any number of operational states (of which a typical UAM operation was divided into approximately 44 different states), compared to rotary-wing assessments which have an upper limit of 12 dynamic operational modes and four static operational modes. The limitations of the fixed-wing method were mostly due to the lack of source directivity definition and the inability to model hover operations. Noise contours in the take-off and landing areas showed the greatest difference between fixed-wing and rotary-wing methods of up to 10-15 dB. Predictions in cruise mode directly underneath the flight path were similar between the two methods, with differences growing with increasing lateral distance from the flight path. The hybrid models were shown to lie somewhere between the full fixed-wing and rotary-wing models, as expected.

The results from AEDT were then compared to results for the same scenario modeled in AAM, using three source directivity profiles: omnidirectional, axisymmetrical, and full 3D. The predicted source noise levels did not contain contributions from broadband noise, which was noted as a potential further development opportunity. Slight differences were found in predictions at different lateral distances between the AEDT and AAM models for the omnidirectional and axisymmetrical directivity profiles, however the full 3D AAM model resulted in significant differences that increased with increasing lateral distance. This suggests that directivity can be an important feature to capture, although the inclusion of broadband noise in the source noise predictions could reduce this difference as it may contribute more to the high frequency content and result in a more uniform directivity profile.

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[16] Domogalla, V. (2025). Propeller landing and takeoff noise in PANAM [Poster]. https://elib.dlr.de/213487/1/ELIB-Eintrag-2025-DomogallaV-213487-Poster.pdf

[17] Rizzi, S.A., Page, J.A., and Cheng, R. (2021). Comparison of Two Community Noise Models Applied to a NASA Urban Air Mobility Concept Vehicle, InterNoise 2021.

[18] Ventura Diaz, P. et al. (2023). High-Fidelity Simulations of NASA's Urban Air Mobility Concept Vehicles, CFC 2023.

3.2.1.4 *Recommendations*

A summary of the pros and cons of each method above is provided in Table 1 below.

Table 1 Summary of pros and cons of modeling tools

Tool type	Software name	Pros	Cons
Integrated tool	AEDT	Widely used to predict community noise from existing aviation noise sources Can support custom UAM noise modeling through the helicopter model and user-supplied NPD data Future updates likely to include additional prediction improvements for mixed ground, terrain and human-made structures, as well as lateral directivity for helicopter modeling.	No native UAM performance models or NPD data No bespoke modeling method for UAM vehicles Fixed-wing method does not include assessment of directivity, which could be critical for UAM Fixed-wing method does not allow for hover operations Rotary-wing method does not allow for enough different operational states to adequately describe the operation of a UAM
	ANCON	Generates flight profiles and flight tracks from historical radar data, increasing the accuracy of the model compared to using standardized flight profiles NPD database is updated yearly based on noise measurements taken at London's largest airports	UK specific and not widely accessible outside the UK Designed for fixed wing aircraft only Similar limitations to AEDT
	IMPACT / STAPES	Web based, reducing computer processor requirements	Unclear whether it can calculate event-based metrics European-focused Designed for fixed wing aircraft only Similar limitations to AEDT
	NORAH2	Designed with future UAM operations in mind Includes propagation effects from buildings and topography	Not yet widely adopted Requires noise hemisphere data, which can be difficult to obtain measured data Unsure if it allows custom noise spheres for novel configurations
	RANE	Has been used for assessment of UAM and novel aircraft configurations Computationally efficient compared to AEDT	Not commercially available Simplified model
Simulation tool	AAM	Models 3D directivity and spectral content Allows assessment of novel configurations Includes propagation effects from buildings and topography	Highly detailed input information required More suitable for research and design-phase analysis
	ANOPP2	Multi-fidelity Allows assessment of novel configurations	Highly detailed input information required More suitable for research and design-phase analysis
	PANAM	Allows assessment of individual noise sources	Not optimized for UAM vehicles or rotorcraft
	SonAIR	Flight radar data used to increase accuracy Includes propagation effects from buildings and topography	Appears to focus on single flight operations Not widely adopted outside Switzerland

Given the scale of dose data required, an integrated model such as AEDT is the preferred approach as it provides a balance between complexity and the need for large scale modeling. It also supports prediction of all the noise exposure metrics required for the derivation of a nationally representative dose-response relationship.

Developing and validating this modeling approach will be the key technical challenge for the study considering the maturity of UAM modeling. Allowance should be provided within the program for model development and validation, including any required noise monitoring.

3.2.2 Propagation in urban environments

UAM aircraft will operate not only at airports but in densely populated environments, including areas near marinas and waterfronts. These operational contexts increase the importance of properly modeling sound propagation, particularly considering reflections from buildings, ground reflections, and propagation over water (which is a hard, sound-reflecting surface in terms of noise propagation).

Complex propagation effects, including propagation over hard ground, are not considered in the ECAC Doc 29 (4th Edition) and ICAO Doc 9911 segmentation methods. While AEDT supports basic terrain modeling and can import digital surface models (DSMs) to account for viewshed, it lacks the capability to simulate the detailed acoustic interactions mentioned above, particularly at locations within a densely populated urban environment. From experience, AEDT also does not handle detailed resolution terrain data very well, so the accuracy of using this method even just for screening effects is limited. AEDT also does not differentiate between hard and soft ground surfaces.

Recent research underscores the importance of these factors if accurate modeling results are to be obtained. A study by Miranda (2023)[19] modeled two NASA UAM concepts in AAM with and without terrain topography and found that including the terrain had a significant effect on sound propagation. Buildings were shown to increase ground-level noise due to build-up from reflections but also decrease noise levels where buildings broke the line of sight between the aircraft and the receptor. The study concluded that "*accounting for far-field propagation effects is crucial for the design and operation of emerging UAM aircraft, given their mission profiles in highly dense population areas at low altitudes*."

Other studies[20,21,22] also demonstrated that buildings altered the predicted ground-level noise, with the impact decreasing with increasing aircraft altitude. One study on helicopter noise from 1973[23] found that urban environments produced noise levels reported to be 7 dB higher than open fields at 200 ft altitude, with the difference decreasing to 5 dB and 4.5 dB at 300 ft and 400 ft, respectively. Hill (2020)[24] anticipated that most

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[19] Miranda, J. N., & Lee, S. (2023). Community Noise Impact of Urban Air Mobility Aircraft with Noise Propagation Effects. In AIAA AVIATION 2023 Forum. AIAA AVIATION 2023 Forum. American Institute of Aeronautics and Astronautics

[20] Yunus, F., Casalino, D., Avallone, F., & Ragni, D. (2023). Efficient prediction of urban air mobility noise in a vertiport environment. Aerospace Science and Technology, 139, 108410.

[21] Gao, Z., Porcayo, A., & Clarke, J.-P. (2023). Developing virtual acoustic terrain for Urban Air Mobility trajectory planning. Transportation Research Part D: Transport and Environment, 120, 103794.

[22] Ismail, M. R., & Oldham, D. J. (2002). The Effect of the Urban Street Canyon on the Noise from Low Flying Aircraft. Building Acoustics, 9(3), 233–251

[23] Kinney, W. A., Pierce, A. D., & Rickley, E. J. (1974). Helicopter noise experiments in an urban environment. The Journal of the Acoustical Society of America, 56(2), 332–337

[24] Hill, B. P., DeCarme, D., Metcalfe, M., Griffin, C. et al. (2020). UAM Vision Concept of Operations (ConOps) UAM Maturity Level (UML) 4. Deloitte Consulting LLP & National Aeronautics and Space Administration. https://ntrs.nasa.gov/citations/20205011091

UAM operations will cruise between 1,500 and 4,000 ft above ground level. Flores (2017)[25] found that the shielding effects of buildings decay with increases in aircraft altitude (they looked at 1640 to 3740 ft), as the line of sight to the aircraft is less likely to be broken by buildings. This means that the propagation effects within the urban environment will be more important for landing and take-off operations, where vehicles are closer to the ground.

Given the acoustically complex environment UAMs will be operating in, more sophisticated digital tools that integrate accurate noise source models with 3D environmental modeling are likely to provide more accurate results.

There are existing, well-developed noise modeling tools that are widely used in the industry for modeling noise propagation within urban environments. These tools can model reflection, diffraction, and ground absorption properties in varying fidelity levels and are used in the industry to predict noise levels and exposure from other infrastructure noise sources, like rail and road traffic, as well as bespoke noise sources in complex environments. Two potential options include software packages like SoundPLAN, which adopts numerous other empirical methodologies alongside aviation noise, and Treble, which uses a combination of physics-based and geometry-based solvers. An overview of the capabilities of the differences and limitations between these is included below.

3.2.2.1 SoundPLAN

SoundPLAN is a modular environmental noise modeling software that is widely used to create 3D noise models and noise maps from various noise sources, including aircraft, road, rail, and industrial operations. SoundPLAN—much like its rivals CadnaA and Predictor LimA—is predominantly used to support the assessment of noise impacts required through regulation, for example, as part of an environmental impact assessment required through the National Environmental Policy Act (NEPA). It supports geo-referenced input data, including terrain, buildings, and noise source information. The noise propagation methodology follows ISO 9613-2[26] and CNOSSOS-EU[27], allowing support for ground attenuation, atmospheric absorption, screening, and reflections from hard surfaces. The aircraft noise module methodology is compliant with ECAC Doc 29.

SoundPLAN's industrial module has the capability to model a single lumped noise source with one-third octave and octave band data and full 3D directivity. Optionally it can include multiple point sources to represent the various noise-generating elements associated with a single aircraft, again each source with full 3D directivity. This source separation would allow the determination of the dominant noise source during each operational mode. The noise source could be placed at a series of discrete points, each representing a distinct part (and time) of an operation, with different noise source characteristics relevant to that operational mode at each point. The noise levels at receptor points would then be determined for each noise source point and could be analyzed together to determine the overall noise level.

The aviation module uses segmented flight paths and emission profiles. SoundPLAN supports the import of radar flight tracks and is linked to the ANP database. While the aviation-specific module supports both fixed-wing and helicopter noise modeling, only the helicopter noise models include reflection and screening effects from buildings. Calculations can be made at single points, grid noise maps at any altitude, cross-sectional grid maps, and façade noise maps.

SoundPLAN, et al. can calculate single event levels, such as the L_{max}, or exposure-based metrics such as L_{eq}.

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[25] Flores, R., Gagliardi, P., Asensio, C., & Licitra, G. (2017). A Case Study of the Influence of Urban Morphology on Aircraft Noise. Acoustics Australia, 45(2), 389–401.

[26] International Organization for Standardization [ISO] (1996) ISO 9613-2:1996 Acoustics — Attenuation of sound during propagation outdoors — Part 2: General method of calculation. Geneva: ISO.

[27] Kephalopoulos, S., Paviotti, M. and Anfosso-Lédée, F. (2012) Common Noise Assessment Methods in Europe (CNOSSOS-EU). EUR 25379 EN. Luxembourg: Publications Office of the European Union. Available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC72550

The main limitation of SoundPLAN and its rivals is that they use simplified, empirical propagation models, like ISO9613-2 or CNOSSOS-EU, which are generalizations compared to wave-based solvers, such as Treble.

3.2.2.2 Treble

Treble is an acoustic simulation platform that combines wave-based and geometrical acoustic solvers. While it was predominantly created for the assessment of internal acoustic scenarios, it could be adapted for environmental acoustics by defining a fully sound absorbing box around the urban study area using a Perfectly Matched Layer (PML) to avoid reflections. It simulates full 3D wave propagation, including diffraction, scattering, and interference.

Source noise levels can be input as one-third octave band spectra with full 3D directivity profiles. However, the following warning from the Treble website should be noted: "*The source directivity will only be applied to the geometric acoustics solver. In the wave-based solver all sources are omnidirectional. An update to add directivity to sources in the wave solver will be implemented in 2025*."

Similarly to SoundPLAN, the noise source could be placed at a series of discrete points, with different noise source characteristics relevant to the operational mode at each point and a separate calculation run for each source location. The computational time required would be more intensive than SoundPLAN, but more accurate propagation results would be obtained. Therefore, the use of Treble could be considered in areas closer to communities, such as near vertiports, where take-off and landing operations occur close to buildings.

It is understood that Treble Tech in conjunction with the Danmarks Tekniske Universitet (DTU), are developing capabilities to officially support urban environment noise modeling in future versions. However, there is no committed timeline for this, and research is anticipated to take many years before the software is updated.

3.2.2.3 Modeling Platform

One significant difference between SoundPLAN and Treble is the platform upon which the software runs. SoundPLAN, introduced in 1986, has always been a desktop application. In the current version, data is stored in databases developed in the 2000s to replace the original Borland Database Engine back end. At the time, this was an efficient, standalone option for an embedded desktop application, but it is not designed for the cloud, only works well with a single user, and cannot be easily scaled.

Treble, initially founded in 2020 and released as software in 2023, adopts a modern SaaS (software as a service) model, running a cloud-based service users interact with through a web browser. Although the exact stack Treble use is unknown, the cloud-native software inherently offers significant horizontal scaling of computational resources, allowing massively parallelized calculations. As a resource-managed system, this does require that the input and output and any data used to compare against these will also need to be hosted in the cloud that can introduce data residency issues.

A similar comparison can be made with the software described above: IMPACT is a scalable, web-based, SaaS model compared to AEDT, a single-user, desktop application.

As UAM and sUAS will operate in urban environments, it is recommended that sensitivity tests are conducted between integrated models (e.g. AEDT) and models that can account for complex propagation effects. This is particularly important for areas close to high-rise buildings and large water bodies where UAM vehicles operate at lower altitudes, and especially for model validation based on noise monitoring locations that are within the urban environment. If significant differences are found, consideration should be given to modeling the most sensitive areas around vertiports using these tools.

3.2.3 Data

3.2.3.1 Source noise levels

For conventional aircraft, source noise levels for the integrated tools listed in section 3.2.1.1 (such as AEDT) are typically provided in the form of NPD curves along with a database of aircraft spectral classes. The NPD data detail the noise level for a given vehicle under different operational modes (i.e. departure / approach / overflight) and power settings. The curves are derived from field measurements under specific flight conditions, and so obtaining the data can be costly. This means that not every aircraft configuration or operating mode can reasonably be tested, so NPD curves are typically assigned by proxy to similar aircraft for which there are no measurement data.

For UAM, there is no existing database of measured NPD data and there is no guarantee that this information will be available at the level of detail required for robust predictions (i.e. covering all the operating states that UAM would use) and available for all operating UAM vehicles. Previous work[28,29,30] has derived predicted NPD curves based on concept UAM vehicle design and operations using the NASA tools ANOPP2 and CAMRAD II. Other work[31,32] has verified a framework that predicts NPD data for different novel vehicles by taking an existing NPD curve of a baseline reference vehicle and applying a delta function that is derived from changes in aircraft technology and/or operations. The latter was shown to give good agreement when used to predict the NPD curves of existing, certified aircraft. The accuracy of these models will likely depend on the level of information available about the various technological and operational differences between the modeled and measured UAM vehicles.

If NPD data is required for the chosen community noise modeling methodology, our recommendations are to:

- Use measured NPD data where possible. If requesting NPD data from OEMs, consider a cost-efficient approach in which the number of aircraft configurations and operation conditions is reduced to not burden OEMs.
- Where appropriate, use existing NPD data as proxy. This is standard practice in existing noise modeling tools and processes.
- Where no measured NPD data is available, predictions of NPD curves could be made, provided the methodology is validated and/or calibrated to available measured NPD data.

Source noise levels can also come in the form of noise hemispheres detailing the sound pressure level at a given distance from the source, inherently including a description of the source directivity. These are typically used in the simulation tools listed in section 3.2.1.2. The level of data required for this is much higher than for NPD curves and therefore obtaining measurement data of noise hemispheres is less likely. Even if available from OEMs, the resolution of the data will likely differ between vehicle models (in terms of both frequency content and spatial resolution). However, due to the inclusion of the directivity profile, this data would yield more

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[28] Rizzi, S., & Rafaelof, M. (2021). Community noise assessment of urban air mobility vehicle operations using the FAA Aviation Environmental Design Tool. INTER-NOISE and NOISE-CON Congress and Conference Proceedings, 263(6), 450–461

[29] Rizzi, S. A., & Rafaelof, M. (2023). On the Modeling of UAM Aircraft Community Noise in AEDT Helicopter Mode. In AIAA AVIATION 2023 Forum. AIAA AVIATION 2023 Forum. American Institute of Aeronautics and Astronautics

[30] Rizzi, S. A., Letica, S. J., Boyd, D. D., Jr., & Lopes, L. V. (2024). Prediction of Noise-Power-Distance Data for Urban Air Mobility Vehicles. Journal of Aircraft, 61(1), 166–182

[31] Synodinos, A. P., Self, R. H., & Torija, A. J. (2018). Framework for Predicting Noise–Power–Distance Curves for Novel Aircraft Designs. Journal of Aircraft, 55(2), 781–791

[32] Amargianitakis, D. C., Self, R. H., Torija, A. J., Proença, A. R., & Synodinos, A. P. (2024). Toward Estimating Noise–Power–Distance Curves for Propeller-Powered Zero-Emission Hydrogen Aircraft. Journal of Aircraft, 61(2), 485–502

accurate modeling results. This level of detail would also be required if complex propagation effects (such as reflections and diffraction from buildings in the urban environment) were to be considered.

To be consistent with other aircraft modeling tools, a frequency range covering the third-octave frequency bands between 50 Hz and 10 kHz is recommended, with a spatial resolution of ten degrees.

Previous work[33] has derived predicted noise hemispheres based on concept UAM vehicle design and operations using the NASA tools ANOPP2 and CAMRAD II. If source hemispheres are required for the chosen community noise modeling methodology, our recommendation is similar to that for NPD curves, noting that the need for predictions instead of measured data will be greater, and the amount of measured data available for verification purposes might be very limited.

3.2.3.2 Flight path information

The flight path information required includes x,y,z coordinates of the flight trajectory and VTOL operations, and the type and number of operations that fly along each flight path during different periods of the day (day, evening, night).

For conventional aircraft, flight paths are typically defined with a route centerline and up to eight subtracks to represent dispersion around the centerline. A similar approach could be taken to model UAM operations. As the community noise survey will be conducted after UAM aircraft have been operational for approximately 12 months, radar or other tracking data for the operations that occurred during this initial 12-month period should be analyzed to define route centerlines and dispersion.

3.2.3.3 Aircraft performance

Details of the aircraft performance during the various operational conditions will be required to carry out the noise modeling. This could include the operational mode of the aircraft, configuration, weight, RPM of the rotors, and velocity. Additional factors could be identified when UAM noise certification procedures are finalized.

Consideration should be given to the variance in these parameters and whether they need to be modeled. For example, with multiple UAM operations occurring within a city, it could be the case that individual vehicles need to slow down to let another vehicle pass, or to let another vehicle finish a take-off / landing maneuver. A recent study[34] introduced the concept of a ‘loitering penalty’ after they found that the speed of the vehicle was correlated with annoyance, i.e. slow fly-bys and fast take-offs were associated with increased annoyance.

3.2.3.4 Factors affecting noise propagation

Terrain data can be downloaded across the US from the United States Geological Survey. The data is available in a range of resolution scales (typically 1 m to 30 m). Terrain data can come in one of three main formats: a digital elevation model (DEM), digital terrain model (DTM) or a digital surface model (DSM). A DEM represents the bare earth’s surface without natural (e.g. rivers) and human-made features; a DTM represents the earth’s surface with added terrain features compared to the DEM but still without any human-made features; and a DSM represents the elevation of all surfaces, including buildings and vegetation.

Consideration should be given to using terrain data in any community noise model, as it has been shown to have potentially significant effects on the predicted noise levels[19]. Whether this is the DEM, DTM, or DSM is likely

[33] Rizzi, S. A., Page, J., & Cheng, R. (2021). Comparison of two community noise models applied to a NASA urban air mobility concept vehicle. INTER-NOISE and NOISE-CON Congress and Conference Proceedings, 263(6), 787–798

[34] Kawai, C., Jäggi, J., Georgiou, F., Meister, J., Pieren, R., & Schäffer, B. (2024). How annoying are drones? A laboratory study with different drone sizes, maneuvers, and speeds. In Quiet Drones 2024.

to depend on how close the noise source is to human-made features (i.e. buildings) and so scenario testing of these three options is recommended to quantify the differences.

Buildings data can be downloaded for certain US cities for free through the website CADmapper[35]. Information for other geographical areas is available for a fee, or alternative software could be used. Building height information can then be derived from subtracting the DTM (or DEM) from the DSM.

The input data required depends on the chosen noise modeling methodology. It is recommended to use NPD data based on measured source noise data where possible, noting that it will likely not be possible to have sufficient data for all vehicle types and operational modes. In these cases, prediction methods can be suitable provided they are validated against measured data.

When requesting NPD data from OEMs, consider a cost-efficient approach in which the number of aircraft configurations and operation conditions is reduced to not burden OEMs and to facilitate collaboration.

If UAM vehicles operate on less well-defined flight paths than conventional aircraft, consideration could be given to tracking UAM operations at the beginning of the survey period to work out realistic typical flight routes and dispersion tracks.

Similarly, tracking could provide useful information on the variance in flight speed and aircraft configuration at various points in the flight path relative to the 'standard' procedures.

3.2.4 Ambient sound environment characterization

UAM will operate within urban environments where there are varying and multiple existing noise sources (e.g. road traffic, industrial noise sources), some of which could dominate UAM noise. Work done under the CAELUS[36] project found that the existing ambient noise level influenced the annoyance response for drone-related noise. Similarly, Lotinga (2025)[37] used the level difference between drone and ambient noise as a predictor of community annoyance. It will be important, therefore, to characterize the existing ambient noise climate across the study area to determine relationships to annoyance or audibility, and to aid the determination of locations for noise monitoring.

Baseline ambient noise levels should be collected in L_{Aeq} and L_{den} metrics to easily compare to the predicted UAM noise levels and to determine the number of events that exceed the ambient noise level. This would also provide insight into the variation of noise levels throughout the day, evening, and night-time periods.

Strategic noise mapping has been collated across the US (where available) and can be downloaded from the US Department of Transport (USDoT) through the National Transportation Noise Map[38]. This shows the results of simplified noise models for noise levels associated with road, rail, and aviation transportation movements in the $L_{Aeq,24hr}$ noise metric. However, the USDoT website notes it is "intended for the tracking of trends and should not be used to evaluate noise levels in individual locations and/or at specific times."

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[35] https://cadmapper.com/

[36] Woodcock, J., Thomas, A., Maldonado, A.L., McLeod, L., Sharp, C., Hiller, D. and Smith, F. (In Press). Human response to eVTOL drone sound: An online listening experiment exploring the effects of operational and contextual factors. Frontiers in Acoustics.

[37] Lotinga, M. J. B., Green, M. C., & Torija, A. J. (2025). Human perception and response to sound from unmanned aircraft systems within ambient acoustic environments. Npj Acoustics, 1(1)

[38] https://maps.dot.gov/BTS/NationalTransportationNoiseMap/

Blue Ridge Research and Consulting (BRRC) have developed a hybrid machine learning and physics-based model[39] to predict the average ambient sound level across the US due to noise produced by humans (including transportation noise), animals, and water. The model was trained with 1.5 million hours of noise measurements taken by the National Park Service, the Environmental Protection Agency, and in-house teams, and environmental variables such as population density, land cover, and climate. The noise data is provided as the L_{50}, which is the noise level exceeded 50% of the time, commonly referred to as the median noise level and is different from the L_{eq}.

Baseline ambient noise levels should be measured at selected locations within the study area and used to calibrate larger scale noise maps (such as BRRC's AMBIENT model) that are available for the whole study area. These could be designed to match the locations that are identified for the noise monitoring.

3.3 Noise monitoring and data collection

UAM and drones are likely to operate under Part 135[40] of National Airspace System (NAS), which currently regulates air carriers and operators providing commuter and on-demand services for aircraft below 19 passengers or a maximum payload capacity of 6,000 pounds. As such, the Part 36[41] type certification would be applied to define noise emission requirements. However, Part 36 might not be sufficient to characterize the noise exposure of UAM over the entire flight profile. FAA recognizes this challenge and suggests a supplementary measurement approach[42], dedicated to drones and potentially applicable to UAM.

Recent studies have shown that noise modeling for conventional aircraft using default assumptions in AEDT can underpredict L_{Amax} by around 3 dB and the sound exposure level (SEL, the total sound energy of a noise event normalized to one second) by 2 dB[43]. One approach to improving the accuracy of aircraft noise models is to calibrate the NPD data for individual aircraft in the model using data from long-term noise monitoring. This is a regulatory requirement in some countries[44] and ensures that the model reflects local operations.

The scope and requirements for noise monitoring over the duration of the project should be established early in the three-year lead in phase. The type of monitoring required for community tests may include:

- Long-term monitoring to establish baseline ambient conditions and support model calibration over time
- Short-term, high-resolution measurements focused on specific UAM vehicle operations, enabling detailed characterization of acoustic signatures
- Meteorological data
- Vehicle operation data, including aircraft trajectory, speed, weight, and flight condition

[39] Blue Ridge Research and Consulting, LLC, n.d. AMBIENT: Hybrid Machine Learning and Physics-Based Noise Modeling Tool. Available at: https://www.blueridgeresearch.com/noise-models

[40] Federal Aviation Administration, Title 14 of the Code of Federal Regulations (14 CFR) Part 135 - Air Carrier and operator Certification

[41] Federal Aviation Administration, Title 14 of the Code of Federal Regulations (14 CFR) Part 36 – Noise Standards: Aircraft Type and Airworthiness Certification

[42] Hobbs, C., Susumu S., Scholten A. & Robinette B. (2024). Measuring drone noise for environmental reviews. Inter-noise 24, Nantes, pp. 9451-9462(12)

[43] Rindfleisch, T. C., Alonso, J. J., Jackson, D. C., Munguía, B. C., & Bowman, N. W. (2024). A large-scale validation study of aircraft noise modeling for airport arrivals. The Journal of the Acoustical Society of America, 155(3), 1928-1949.

[44] Civil Aviation Authority (2021), CAP2091: CAA Policy on Minimum Standards for Noise Modelling

A benchmarking exercise to evaluate existing Commercial Off-The-Shelf (COTS) solutions for noise monitoring should be undertaken early in the project. This benchmark should consider factors such as cost-effectiveness, technical complexity, durability, connectivity, and operational autonomy. One widely adopted COTS solution is the Airport Noise and Operations Monitoring System (ANOMS) by Envirosuite[45], which integrates noise monitoring with aircraft tracking data. ANOMS is used at many international airports and shows how commercial systems can deliver reliable performance with minimal human intervention. It supports long-term unattended operation, remote data access, and integration with radar or ADS-B (Automatic Dependent Surveillance – Broadcast, an automatic telemetry feed broadcast in flight by aircraft) feeds.

To enhance spatial coverage and reduce costs, Internet of Things (IoT)-based noise monitoring systems could be deployed. These systems typically use low-cost microelectromechanical systems (MEMS) microphones and single board computers or microcontrollers. A notable precedent is the SONYC (Sounds of New York City) project[46], which developed a city-scale acoustic sensor network using low-cost hardware and machine learning to detect and classify urban noise sources, including construction and road traffic. A similar machine learning approach could be used to identify UAM and sUAS events.

Low cost IoT noise monitors could be combined with weather stations and ADS-B receivers to correlate meteorological conditions and aircraft positions with noise events[47]. This approach could enable dense, distributed monitoring systems that are scalable (deployed in multiple community locations), affordable (a fraction of the cost of certified Class A systems), flexible (battery-powered or solar powered for remote use), and connected (LoRaWAN, a Long Range Wide Area Network, or cellular network for real-time data transmission).

Based on 14 CFR part 36, the FAA recommends the following adapted procedure to measure ‘en route’ noise from drone flights:

- Flight should be parallel to direction of wind
- Microphone distances are located below flight path and laterally at 50 ft, 100 ft, and doubling thereafter until noise level is less than 6 dB above ambient level
- At least six sets of up- and down-wind passes should be measured
- $L_{Amax,S}$ should be 15 dB above the ambient

To characterize take-off and landing, FAA recommends the following procedure:

- Vehicle should follow operational profile of each phase of flight
- Measurement locations should include undertrack, locations in the opposite direction, and locations in either lateral direction.
- The first location should be at the closest safe distance and doubling thereafter until the vehicle sound level is equal to the ambient level.

Noise monitoring should be used for the validation of the noise modelling tools and to provide site specific model calibration data.

Noise monitoring data can also be used to validate ambient noise models.

[45] ANOMS NoiseDesk: https://envirosuite.com/platforms/aviation/anoms

[46] Sounds of New York City: https://wp.nyu.edu/sonyc/

[47] Liu, J., Sun, S., Tang, K., Fan, X., Lv, J., Fu, Y., ... & Zeng, L. (2025). IoT-Based Airport Noise Perception and Monitoring: Multi-Source Data Fusion, Spatial Distribution Modeling, and Analysis. Sensors, 25(8), 2347.

3.4 Metrics

Dose-response relationships for transportation noise—including conventional aviation—typically use long-term average outdoor L_{Aeq}-based metrics as the primary dose metric. Research from the UK Civil Aviation Authority[48,49] indicates there is no evidence to suggest that any noise indicators correlate better with the principal health effects from aircraft noise (daytime annoyance and night-time sleep disturbance) than the L_{Aeq} metric.

Single-event metrics like $L_{Amax,S}$ and SEL, in compliance with 14 CFR part 36, Appendix J, can be relevant for specific effects such as sleep disturbance and awakenings. Similarly, event-count metrics such as number-above (N_x) or the UK CAA overflight metric[50] can quantify the impact of frequent noise events that are not fully reflected in energy-based averages.

In addition, several psychoacoustic and sound quality metrics such as loudness, sharpness, fluctuation strength, roughness, and impulsiveness have shown correlations with annoyance in laboratory and controlled field studies[51]. The community noise survey presents an opportunity to explore how these metrics perform in a real-world setting. However, because many of these metrics require sound pressure time histories for calculation it may not be feasible to calculate them for all respondents using standard modeling tools. A focused investigation could be conducted at a single site or for a subset of respondents to determine if these metrics perform better than L_{Aeq} based metrics.

It is recommended that the primary dose-response relationship is formulated using long-term, average outdoor L_{Aeq}-based metrics to support international comparison and alignment with national aviation policy.

Event-based metrics such as L_{Amax} and N_x should also be explored. While full-scale modeling of psychoacoustic metrics may not be feasible, their inclusion in a subset of sites could provide valuable insights into the efficacy of these metrics to describe annoyance.

[48] Civil Aviation Authority (2021), CAP1506: Survey of Noise Attitudes 2014: Aircraft Noise and Annoyance, Second Edition

[49] Civil Aviation Authority (2021), CAP2161: Survey of Noise Attitudes 2014: Aircraft Noise and Sleep Disturbance

[50] Civil Aviation Authority (2017). CAP1498: Definition of overflight.

[51] Lotinga, M. J., Ramos-Romero, C., Green, N., & Torija, A. J. (2023). Noise from unconventional aircraft: a review of current measurement techniques, psychoacoustics, metrics and regulation. Current Pollution Reports, 9(4), 724-745.

4. Response-Related

4.1 Aims and objectives

To quantify response, a questionnaire and associated survey methodology are required. The primary purpose of the questionnaire is to measure annoyance responses from residents exposed to noise from UAM and sUAS operations. The questionnaire should be designed and administered in such a way as to measure annoyance responses without introducing bias and in a way that is suitable for analysis alongside noise dose predictions or measurements to derive dose-response relationships. The questionnaire should allow for an in-depth analysis of annoyance due to UAM and sUAS noise by measuring responses of overall annoyance and separate responses for different categories of UAM noise (i.e. different vehicle types and operational modes). To account for any observed differences in annoyance at similar levels of noise exposure, questions beyond annoyance should include the respondents' attitudes to UAM, situational factors, and socio-demographic characteristics. The key design principles for the questionnaire should include:

- Ensuring comparability with established noise annoyance research (e.g. following guidance in ISO/TS 15666[52]).
- Avoiding design-induced bias, particularly in how the survey is introduced and how questions are sequenced.
- Capturing all relevant quantitative (and qualitative) data to support robust dose–response modeling and contextual interpretation.
- Recognizing that UAM is a novel source of noise, careful definition, and framing to ensure comprehension without biasing responses.

Following data collection, statistical methods are required to derive dose-response relationship and conduct post-hoc analyses.

The following subsections set out these considerations in further detail.

4.2 Analysis methods and tools

4.2.1 Differences across UAM configurations

UAM vehicles operate over a range of configurations (e.g. tiltrotors, lift-plus-cruise) and operational modes (e.g. take-off, landing, hover, and overflight), each with different acoustic characteristics that may elicit different annoyance responses. Community noise studies for other transportation sources typically do not differentiate between operational modes. For example, dose-response relationships for conventional aircraft are not derived separately for propulsion type (e.g. jet vs turboprop) or operational mode (e.g. take-off, landing, or overflight).

A UK community noise and vibration study on railway noise and vibration[53] successfully derived dose-response relationships for different railway sources. The questionnaire used in the study began by asking respondents about general annoyance from all railway sources (see Figure 1). This was followed by questions on specific sources (e.g. passenger vs freight trains). The study successfully derived both a generalized dose-response

[52] ISO (2021). ISO/TS15666:2021, Acoustics—Assessment of Noise Annoyance by Means of Social and Socio-Acoustic Surveys (International Organization for Standardization, Geneva; Switzerland).

[53] Waddington, D. C., Woodcock, J., Peris, E., Condie, J., Sica, G., Moorhouse, A. T., & Steele, A. (2014). Human response to vibration in residential environments. The Journal of the Acoustical Society of America, 135(1), 182-193.

relationship along with source-specific dose-response relationships for passenger and freight trains[54]. The dose-response relationship for passenger trains was found to be lower than the generalized relationship, while the relationship for freight trains was higher. This suggests that people can both integrate and distinguish annoyance across different categories of sources within a broader source class.

Thinking about the last 12 months or so, when indoors at home, how bothered, annoyed or disturbed have you been by feeling vibration or shaking or hearing or seeing things rattle, vibrate or shake caused by the railway, including passenger trains, freight trains, track maintenance or any other activity from the railway, would you say not at all, slightly, moderately, very or extremely?

Don't notice	Not at all	Slightly	Moderately	Very	Extremely
	1	2	3	4	5

Thinking about the last 12 months or so, when indoors at home, how bothered, annoyed or disturbed have you been by feeling vibration or hearing or seeing things rattle, vibrate or shake caused by **[insert sources below]**? Would you say not at all, slightly, moderately, very or extremely?

[Repeat question for all sources]

Source	Don't notice	Not at all	Slightly	Moderately	Very	Extremely
Passing passenger trains		1	2	3	4	5
Passing freight trains		1	2	3	4	5
Railway maintenance		1	2	3	4	5
Other railway activity **[Record below]**		1	2	3	4	5
______________		1	2	3	4	5

Figure 1 Source specific railway noise and vibration annoyance questions used in UK community noise and vibration study.

It is recommended that the annoyance section of the questionnaire begins with a general question on annoyance from UAM and sUAS operations, followed by more detailed questions about specific vehicle configurations and operational modes. This structure allows for both generalized and disaggregated analysis of community response.

4.2.2 Statistical dose-response modeling methods and meta-analysis

A key consideration for the formulation of dose-response relationships is the statistical model used. Early work on the development of dose-response relationships for transportation noise[55,56] used third-order polynomial curve fits to describe the relationship between noise exposure (expressed as L_{dn}) and percent highly annoyed (%HA,

[54] Sharp, C., Woodcock, J., Sica, G., Peris, E., Moorhouse, A. T., & Waddington, D. C. (2014). Exposure-response relationships for annoyance due to freight and passenger railway vibration exposure in residential environments. The Journal of the Acoustical Society of America, 135(1), 205-212.

[55] Schultz, T. J. (1978). Synthesis of social surveys on noise annoyance. The Journal of the Acoustical Society of America 64, 377-405.

[56] Fidell, S. (1989). Updating a Dosage-Effect Relationship for the Prevalence of Annoyance Due to General Transportation Noise. DTIC Document.

the proportion of respondents expressing annoyance in the upper 28% of the annoyance scale, see section 4.4 for further discussion).

However, regression of a continuous independent variable (i.e. noise exposure) onto a binary or categorical dependent variable (i.e. %HA) violates the assumptions of ordinary least squares (OLS) regression, leading to potentially biased coefficient estimates and standard errors[57]. There are well-established methods for regressing continuous data onto categorical data which overcome these issues. One such method is logistic regression, which has been used by both the FICON study[58] and the Neighborhood Environmental Survey (NES)[59] to derive dose-response relationships for conventional aviation noise.

Logistic regression is specifically designed for dependent variables with binary outcomes, making it a suitable method for modeling dose-response relationships where annoyance is expressed as %HA. The model estimates the probability that an individual will be highly annoyed at a given level of noise exposure. This is achieved by transforming a linear combination of predictor variables (e.g. DNL or DENL) using a logistic function, which maps the output to a probability between 0 and 1.

Logistic regression has several advantages in the context of community noise studies. It provides easily interpretable coefficients (e.g. odds ratios), accommodates non-linear relationships between exposure and response, and allows for the estimation of confidence intervals around predicted probabilities. It is also widely supported in standard statistical software packages.

An alternative approach to logistic regression is the use of multilevel grouped regression. Multilevel grouped regression[60] is a statistical modeling technique that accounts for the hierarchical structure of data, such as individuals nested within studies or communities. Unlike standard regression models that assume independence of observations, multilevel models explicitly incorporate random effects to capture variability both within and between groups. This is useful for data from community noise studies, where responses vary due to individual differences (e.g. noise sensitivity, fear, demographics) and contextual factors (e.g. existing ambient levels).

The annoyance response is modeled as a function of noise exposure (e.g. DNL or DENL), with random intercepts and slopes assigned to each group (e.g. study or subject). This allows the model to estimate both population-level and group-specific effects. For example, Miedema and Oudshoorn (2001)[61] applied multilevel regression to derive dose-response relationships for aircraft, road, and rail noise, accounting for between-study variation. The method has also been applied by TNO and the FAA to develop dose-response relationships for aircraft noise annoyance[62].

It is recommended that multilevel grouped regression is explored to allow differences between sites/communities to be accounted for in the model.

[57] Agresti, A. (1990). Categorical data analysis (Wiley).

[58] Federal Interagency Committee on Noise (FICON) (1992). Federal Agency Review of Selected Airport Noise Analysis Issues, Report for the Department of Defense, WA, DC., pp. 1–192.

[59] https://www.faa.gov/regulations_policies/policy_guidance/noise/survey

[60] Groothuis-Oudshoorn, C. G., & Miedema, H. M. (2006). Multilevel grouped regression for analyzing self-reported health in relation to environmental factors: The model and its application. Biometrical Journal, 48(1), 67-82.

[61] Miedema, H. M., & Oudshoorn, C. G. (2001). Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals. Environmental health perspectives, 109(4), 409-416.

[62] TNO (2011). Dose-response relationship between DNL and aircraft noise annoyance: Contribution of TNO.

4.3 Survey methods

4.3.1 Study type

Community noise surveys are typically cross-sectional, resulting in data for a snapshot of a population at a specific point in time. Research indicates that when noise exposure changes suddenly (such as with the introduction of a new noise source), the annoyance response is higher than that predicted from steady-state dose-response relationships[63,64,65]. For example, longitudinal studies around Schiphol and Frankfurt airports observed sustained elevated annoyance levels for at least two years following the introduction of new runways, even when controlling for non-acoustic factors such as attitudes and expectations[66,67]. Annoyance due to aircraft noise has also been observed to increase over time[68,69]. Considering this, the period of time that a new source has been operating is an important consideration if the goal of the study is to derive a representative steady state dose-response relationship.

The recommended annoyance questions in ISO/TS 15666 measure annoyance with reference to the "*last 12 months or so*" (the standard does not explicitly justify the 12-month timeframe). To ensure that the derived dose-response relationship reflects a steady-state relationship, it is recommended that UAM and sUAS operations be established and stable in the community for at least 12 months prior to conducting the survey.

In addition to the primary cross-sectional survey, the project presents a valuable opportunity to incorporate a longitudinal component to investigate changes in community response over time. A subset of participants could be resurveyed at multiple time points (e.g., pre-introduction, six months post-introduction, and 12–24 months post-introduction of UAM operations) to investigate trends in annoyance after the introduction of a new sound source. This data would inform the interpretation of cross-sectional findings and contribute to the broader evidence base on noise adaptation and policy planning for emerging aviation technologies.

It is recommended that the study is primarily cross-sectional in design. Additional longitudinal studies could be deployed at a subset of communities to study the change of annoyance response over time.

4.3.2 Survey mode

The choice of survey mode (the method used to collect data from respondents) is a fundamental design decision in questionnaire-based research. Surveys can be administered through face-to-face interviews, telephone interviews, postal surveys, and web-based surveys. The mode of administration affects response rates and

[63] Brown, L., & van Kamp, I. (2008). Estimating the magnitude of the change effect. In 9th International Congress on Noise as a Public Health Problem (ICBEN).

[64] Brown, A. L., & Van Kamp, I. (2009). Response to a change in transport noise exposure: A review of evidence of a change effect. The Journal of the Acoustical Society of America, 125(5), 3018-3029.

[65] Van Kamp, I., & Brown, A. L. (2013). Response to change in noise exposure: an update. In Acoustics 2013 Victor Harbor: Science, Technology and Amenity. Australian Acoustical Society.

[66] Brown, A. L., & Van Kamp, I. (2009). Response to a change in transport noise exposure: A review of evidence of a change effect. The Journal of the Acoustical Society of America, 125(5), 3018-3029.

[67] Schreckenberg, D., Faulbaum, F., Guski, R., Möhler, U., & Spilski, J. (2016, August). Effects of aircraft noise on annoyance and sleep disturbances before and after expansion of Frankfurt Airport-Results of the NORAH study, WP 1'Annoyance and quality of life'. In INTER-NOISE and NOISE-CON Congress and Conference Proceedings (Vol. 253, No. 7, pp. 997-1006). Institute of Noise Control Engineering.

[68] Guski, R. (2004). How to forecast community annoyance in planning noisy facilities. Noise Health 6, 59–64.

[69] van Kempen, E. E. M. M., and van Kamp, I. (2005). Annoyance from air traffic noise: Possible trends in exposure-response relationships. Report No. 01/2005 MGO EvK, reference 00265/2005, National Institute of Public Health and the Environment, Bilthoven, The Netherlands.

introduces potential sources of bias[70]. Each mode has advantages and limitations, which are discussed in the subsections below.

The mode of administration should be determined before finalizing the questionnaire, as it imposes constraints on the structure of the questionnaire. For example, self-administered postal surveys may require simpler routing structures, while interviewer-led modes can accommodate a more complex routing structure.

4.3.2.1 In-person surveys

In-person surveys, conducted by trained interviewers, are often considered the gold standard for data collection. Interviewers can clarify ambiguous questions in real time, helping to ensure that respondents interpret questions as intended. This is especially valuable in studies involving novel technologies like UAM, where respondents may be unfamiliar with key concepts. Interviewers can ensure that definitions and distinctions between technologies are clearly understood. In-person surveys also reduce common data quality issues such as missing responses, ambiguous markings and illegible handwriting.

Because interviewers guide the process, in-person surveys allow for more complex questionnaire designs. For example, routing can be used to probe specific issues in greater detail, such as asking follow-up questions about particular noise sources if general annoyance is reported.

In-person surveys also offer high coverage, as interviewers can directly approach all eligible households. They typically yield the highest response rates, as individuals are less likely to refuse a face-to-face request than to ignore a phone call or discard a mailed questionnaire.

However, this mode of survey administration is resource-intensive and expensive. Additionally, there is a potential for social desirability bias, where respondents tailor their answers to align with perceived social norms. While this is a known potential source of bias for in-person interviews, it is not likely to be an issue for noise annoyance surveys as noise annoyance is not considered to be a socially sensitive issue[71].

4.3.2.2 Telephone surveys

Telephone surveys share many of the benefits of in-person interviews. They are interviewer-led, allowing for clarification of questions and probing for more detailed responses. This can lead to more accurate and complete data than self-administered modes such as postal surveys.

A key limitation of telephone surveys is potential coverage bias, as not all households have landlines and reaching individuals on mobile phones can be difficult. This would reduce representativeness of the resulting dose-response relationship. The sampling strategy for community noise surveys is typically based on reaching a target number of individuals in different noise exposure bands (see section 4.3.4). It may be difficult to obtain telephone numbers for individuals within specific noise exposure bands.

4.3.2.3 Postal surveys

Postal surveys involve mailing paper questionnaires to respondents for self-completion and return. They are less resource-intensive than interviewer-led modes and can be deployed at scale with relatively low cost.

The lack of interviewer support means there is the potential for respondents to misinterpret questions or skip items they find confusing. This can lead to higher rates of incomplete data compared to interviewer led modes. Postal surveys are also vulnerable to self-selection bias as individuals who are more annoyed may be more likely to respond.

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[70] Bowling, A. (2005). Mode of questionnaire administration can have serious effects on data quality. Journal of Public Health, 27(3), 281-291.

[71] Whittle, N., Peris, E., Condie, J., Woodcock, J., Brown, P., Moorhouse, A. T., ... & Steele, A. (2015). Development of a social survey for the study of vibration annoyance in residential environments: Good practice guidance. Applied Acoustics, 87, 83-93.

The ARCP 02-35 study[72] compared postal and telephone surveys in the context of aviation noise annoyance. It found that postal surveys had a higher response rate (35.1% vs. 12.1%) and no significant difference in the percentage of highly annoyed respondents was observed between the two modes. This suggests that, when well-designed, postal surveys can yield high quality data in the context of community noise surveys.

4.3.2.4 Web-based surveys

Web-based surveys offer speed and cost-efficiency as they eliminate printing, mailing, and manual data entry costs. While overall response rates may be lower than other modes, data completeness among respondents is often higher. Studies have shown that web surveys tend to have fewer missing values than paper-based surveys[73].

Web surveys are susceptible to self-selection bias. Respondents are typically younger and more educated than the general population, which can affect the representativeness of the sample[74]. Internet access is not universal, and some communities may be excluded entirely. Additionally, geographic targeting, essential for community noise surveys, is more difficult to implement online.

4.3.2.5 Mixed-mode designs

Mixed-mode designs combine two or more survey modes within a single study to balance the strengths and limitations of each. For example, a study might begin with a postal survey and follow up with telephone interviews for non-respondents or offer both web and paper options to accommodate different respondent preferences.

This approach was taken in the NES which included an initial postal survey and a follow-up telephone survey. The main annoyance question, which was used to derive the dose-response relationship, was asked in the postal survey. The follow-up telephone survey asked detailed questions on a number of areas including respondents' opinions on noise, exposure to aircraft noise, relationship to the airport, concerns about aircraft operations, and views on airport community relations, among others. The response rate for the postal survey was 40.3% of the eligible sample and the response rate for the follow-up telephone interview was 9.1% of the eligible sample (or 22.5% of completed postal surveys)

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[72] National Academies of Sciences, Engineering, and Medicine (2014). Research Methods for Understanding Aircraft Noise Annoyances and Sleep Disturbance. Washington, DC: The National Academies Press.

[73] Ebert, J. F., Huibers, L., Christensen, B., & Christensen, M. B. (2018). or web-based questionnaire invitations as a method for data collection: cross-sectional comparative study of differences in response rate, completeness of data, and financial cost. Journal of Medical Internet Research, 20(1), e24.

[74] Heiervang, E., & Goodman, R. (2011). Advantages and limitations of web-based surveys: evidence from a child mental health survey. Social Psychiatry and Psychiatric Epidemiology, 46, 69-76.

4.3.2.6 Summary

The choice of survey mode has important implications for data quality, response rates, coverage, and cost. A summary of the advantages and disadvantages of each survey mode discussed in this section is provided in Table 2.

Table 2 Advantages and disadvantages of different survey administration modes

Mode	Advantages	Disadvantages
In-person	High response rates; Clarification of questions; Supports complex routing; High data quality	High cost and time requirements; Potential for social desirability bias
Telephone	Interviewer-led; Clarification possible; Lower cost than in-person	Coverage bias (landline/mobile access); Limited geographic targeting
Postal	Cost-effective; Broad reach; Familiar format	No clarification of questions; Higher item non-response; Self-selection bias
Web-based	Low cost; Fast deployment; High data completeness	Lower response rates; Digital divide limits coverage; Self-selection bias
Mixed-mode	Combines strengths of multiple modes; Improves coverage and response rates	Potential for mode effects in responses

In-person questionnaires are the gold standard data collection method for the social survey. As well as high coverage and response rate, the main advantage for a community survey on UAM noise would be that the interviewer can clarify any ambiguities or misunderstandings around the definitions of UAM and sUAS used in the questionnaire. However, it is recognized that given the scale of surveys required, in-person surveys are likely to be cost prohibitive.

Postal surveys with follow-up telephone interviews, an approach that was used successfully in the NES, is likely to be the most pragmatic approach. The main annoyance question(s) can be asked in the postal survey, with more detailed follow up questions on contextual, attitudinal, and situational factors asked in the follow-up telephone interview. However, the definitions of UAM and sUAS used in the postal survey will need to be rigorously tested to ensure they are understandable to the public.

4.3.3 Survey questions

4.3.3.1 Annoyance

Annoyance is the primary response metric for quantifying the community response to environmental noise[75]. The measurement of annoyance in residential environments is governed by the Technical Specification ISO/TS 15666 '*Acoustics — Assessment of noise annoyance by means of social and socio-acoustic surveys*'.

ISO/TS 15666 recommends two questions, along with two rating scales, for the measurement of noise annoyance. The scales result in interval-level measurements which can be used in regression analyses and other statistical analysis techniques.

[75] World Health Organization (2018). The World Health Organization Guidelines for Environmental Noise Exposure for the European Region. World Health Organization Europe, Copenhagen: Denmark.

The first recommended question is posed as follows:

"Thinking about the last (12 months or so), when you are here at home, how much does noise from (noise source) bother, disturb or annoy you?"

The response is recorded on a five-point semantic scale labelled:

- Not at all
- Slightly
- Moderately
- Very
- Extremely

The second recommended question is introduced as:

"This uses a 0-to-10 opinion scale for how much (source) noise bothers, disturbs or annoys you when you are here at home[76]. If you are not at all annoyed choose 0; if you are extremely annoyed choose 10; if you are somewhere in between, choose a number between 0 and 10."

and the following question is posed:

"Thinking about the last (12 months or so), when you are here at home, what number from 0 to 10 best shows how much bothered, disturbed or annoyed by (source) noise?"

The response to this question is recorded on an eleven-point numerical scale labelled "Not at all" (0) to "Extremely" (10).

These questions were designed through the ICBEN group[77,78] to provide valid international comparison of survey results within and between languages; provide a high quality and reliable measure of a general reaction to noise experienced in a residential environment; give transparent results that could be consistently interpreted by survey respondents and policy makers; and be suitable for all questionnaire administration modes including face-to-face, telephone, and self-administered.

[76] The TS clarifies that the terminology "at home" covers inside the home or outdoors at home (for example, in the garden or on the balcony).

[77] Fields, J. M., de Jong, R. G., Gjestland, T., Flindell, I. H., Job, R. S., Kurra, S., ... & Schumer, R. (2001). Standardized general-purpose noise reaction questions for community noise surveys: Research and a recommendation. Journal of Sound and Vibration, 242(4), 641-679.

[78] Clark, C., Gjestland, T., Lavia, L., Notley, H., Michaud, D., & Morinaga, M. (2021). Assessing community noise annoyance: A review of two decades of the international technical specification ISO/TS 15666: 2003. The Journal of the Acoustical Society of America, 150(5), 3362-3373.

Since the publication of these recommendations, the response questions have been used to measure self-reported annoyance in community noise studies for a range of different sources including road, rail, aviation, and wind turbines[79,80,81,82,83,84,85,86].

The previous recommendation from ICBEN and the 2003 version of ISO/TS 15666 was to include both the five-point verbal question and the 11-point numeric question as this was psychometrically more robust, offered greater reliability of assessment, and enabled greater comparison between studies. ISO/TS 15666:2021 relaxes this requirement, acknowledging that it may not always be possible or practical to include both questions. If only one scale is included, ISO/TS 15666:2021 recommends using the 11-point numeric question, as it offers the greatest options for statistical testing and cross-study comparisons.

It is recommended to follow the wording of the annoyance questions in ISO/TS 15666 and to include both the five-point semantic and 11-point numerical response scale.

4.3.3.2 Introducing the survey

The way in which the survey is presented can influence responses and reasons for participation. It is best if noise annoyance surveys are introduced as a survey of neighborhood satisfaction[71] or environmental quality[86]. The introductory section can focus on neighborhood satisfaction before moving onto questions about noise spontaneously. This approach also supports the collection of broader contextual data (e.g. housing, transport, amenities) that may influence annoyance.

It is recommended that the questionnaire be framed as a neighborhood satisfaction/neighborhood environment survey to avoid biasing responses and reasons for participation.

4.3.3.3 Defining the source

To ensure reliability and validity of results, the sources investigated by the survey should be clearly defined for respondents[71]. This is particularly important for novel sources like UAM and sUAS where respondents may be unfamiliar with the technology. Expanded definitions should be supplied, for example the annoyance question could ask about *"…Urban Air Mobility and other Advanced Air Mobility Vehicles, including eVTOL aircraft, air*

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[79] Brink, M., Wirth, K. E., Schierz, C., Thomann, G., and Bauer, G. (2008). Annoyance responses to stable and changing aircraft noise exposure. The Journal of the Acoustical Society of America, 124, 2930-2941.

[80] Michaud, D. S., Keith, S. E., Feder, K., Voicescu, S. A., Marro, L., Than, J., Guay, M., Bower, T., and al, e. (2016). Personal and situational variables associated with wind turbine noise annoyance. The Journal of the Acoustical Society of America, 139, 1455-1466.

[81] Civil Aviation Authority (2017). CAP1506 Survey of Noise Attitudes 2014. (Civil Aviation Authority, London; United Kingdom).

[82] Murakami, Y., Yano, T., Morinaga, M., and Yokoshima, S. (2018). Effects of Railway Elevation, Operation of a New Station, and Earthquakes on Railway Noise Annoyance in Kumamoto, Japan. International Journal of Environmental Research and Public Health, 15, 1417.

[83] Brink, M., Schaffer, B., Vienneau, D., Foraster, M., Pieren, R., Eze, I. C., Cajochen, C., Probst-Hensch, N., Roosli, M., and Wunderli, J. M. (2019). A survey on exposure-response relationships for road, rail, and aircraft noise annoyance: Differences between continuous and intermittent noise. Environment International, 125, 277-290.

[84] Gjestland, T., Gelderblom, F. B., and Fidell, S. (2019). Sample size implications for calculations of community tolerance level values from social surveys of noise-induced annoyance. The Journal of the Acoustical Society of America, 146, 1212.

[85] Morinaga, M., Nguyen, T. L., Shimoyama, K., Yokoshima, S., and Yano, T. (2020). Effects of step change in aircraft noise exposure on activity disturbances: Socio-acoustic surveys around Hanoi Noi Bai International Airport. Acoustical Science and Technology, 41, 590-597.

[86] Miller, N. P., Czech, J. J., Hellauer, K. M., Nicholas, B. L., Lohr, S., Jodts, E., Broene, P., Morganstein, D., Kali, J., Zhu, X., Cantor, D., Hudnall, J., and Melia, K. (2021). Analysis of the Neighborhood Environmental Survey. (U.S. Department of Transportation, Federal Aviation Administration).

taxis, and drone-based delivery systems…" to ensure all sources are covered (sources to be defined in the development of the questionnaire).

These terms should be clearly defined for the respondent and avoid technical jargon or ambiguous terms. Visual aids could be considered, but only if it can be shown that they do not influence responses. Respondents who state that they are annoyed by noise from UAM and sUAS noise in general can subsequently be routed to specific sections in the survey that explore annoyance from different sources in greater depth (see section 4.2.1).

The understandability and interpretability of the source definitions and related questions can be evaluated prior to the full study. This can be achieved through cognitive testing, where a small number of participants are asked to verbalize their thought process while answering the questions. This helps identify misunderstandings, ambiguous wording or unintended interpretations.

In addition, a pilot survey can be conducted with a small, representative sample to assess how well respondents comprehend the source definitions and whether the routing logic functions as intended. Feedback from these pretests should be used to refine the wording, structure and presentation of the questions to ensure clarity and consistency across the target population.

4.3.3.4 Non-acoustic factors

Several studies have highlighted how the dose-response curves for annoyance are influenced by non-acoustic factors such as attitudes, demographic factors, and environmental and contextual factors[87,88,89]. Lotinga[90] provides examples of personal and contextual factors that may be influential in determining subjective responses to UAM and sUAS noise exposure. These include:

- Personal factors
  - Demographic factors
  - Personality traits
  - Expectations connected with demographics and the situational context
  - Sensitivity to noise or other environmental stressors
  - Experience with or attitude towards the sound source type, and what it may represent (e.g. societal benefits)
  - Perception of personal risk (i.e. safety)
  - Economic involvement or benefits
  - Trust in authorities and regulatory protections, and perception of fairness in planning processes
- Contextual factors
  - The nature of the receiving environment, including the ambient soundscape and the visual landscape

[87] Guski, R. (1999). Personal and social variables as co-determinants of noise annoyance. Noise and Health, 1(3), 45-56.

[88] Civil Aviation Authority. (2017). CAP1506 Survey of Noise Attitudes 2014. London; United Kingdom.

[89] Guski, R., Schreckenberg, D., & Schuemer, R. (2017). WHO Environmental Noise Guidelines for the European Region: A systematic review on environmental noise and annoyance. International Journal of Environmental Research and Public Health, 14(12), 1539.

[90] Lotinga, M. J., Ramos-Romero, C., Green, N., & Torija, A. J. (2023). Noise from unconventional aircraft: a review of current measurement techniques, psychoacoustics, metrics and regulation. Current Pollution Reports, 9(4), 724-745.

- The time of day
- The nature or importance of activities being undertaken (and potentially disrupted)
- The presence of other environmental stressor co-exposures associated with the sound source (such as visual impact or odor)
- The strength or sense of community and social cohesion in the area
- Political and industry approaches to communicating, informing, and policy-making in relation to the technology and potential benefits associated with the source
- The activities of and information disseminated by other interested parties, such as civic groups and community campaigners

Community noise studies[91,92,93,94,95] consistently show that night-time noise is rated as more annoying than daytime or general 24-hour exposure. There is an implicit assumption that the standard ISO 15666 annoyance questions (see section 4.3.3.1) measure annoyance integrated over a 24-hour period. Asking respondents to rate annoyance over a 24-hour period may lead to underestimation of annoyance in areas with significant night-time exposure or where day and night noise levels differ substantially. To address this the survey should include additional questions on annoyance at different times of day.

ISO/TS 15666 allows flexibility in assessing time-specific annoyance but recommends that the standard questions be asked first to establish a baseline for comparison. When assessing annoyance during specific periods, the standard advises clearly specifying the hours of interest (e.g. “07:00–12:00” rather than “morning”) to avoid ambiguity and ensure consistency across respondents and contexts.

4.3.4 Sampling

To ensure the resulting dose-response relationship for UAM and sUAS noise is nationally-representative and statistically robust, careful consideration needs to be given to the selection of study areas/communities and the number of respondents within each.

Variability in annoyance responses is expected both between different areas/communities and among respondents within a particular area. Increasing the number of areas/communities included in the study will help to decrease the overall variability attributable to site-specific factors. Conversely, increasing the number of respondents within a given area primarily reduces the variability associated with individual differences. Results from previous community noise surveys should be used to inform required number of areas/communities and respondents to ensure a statistically robust dose-response relationship.

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[91] Wirth, K., Brink, M., and Schierz, C. (2004). Aircraft Noise Annoyance at Different Times of Day," In *Proceedings of the joint meeting of DAGA and CFA*

[92] Öhrström, E., Skånberg, A., Svensson, H., and Gidlöf-Gunnarsson, A. (2006). Effects of road traffic noise and the benefit of access to quietness. Journal of Sound and Vibration 295, 40-59.

[93] Peris, E., Woodcock, J., Sica, G., Moorhouse, A. T., and Waddington, D. C. (2012). Annoyance due to railway vibration at different times of the day. The Journal of the Acoustical Society of America 131, El191-196.

[94] Michaud, D. S., Feder, K., Keith, S. E., Voicescu, S. A., and et al (2016a). Exposure to wind turbine noise: perceptual responses and reported health effects. The Journal of the Acoustical Society of America 139.

[95] Civil Aviation Authority (2017). CAP1506 Survey of Noise Attitudes 2014. (Civil Aviation Authority, London; United Kingdom).

4.3.4.1 Site selection

Potential areas/communities for the survey should be selected based on defined eligibility criteria. As an illustrative example, the criteria used to select airports for the NES were that the airport was in the contiguous US, had at least 100 average daily operations, and had at least 100 people within the higher noise exposure bands.

Following the application of these eligibility criteria, the NES utilized a balanced sampling approach to select 20 airports for inclusion in the study. This method ensured that the chosen sample collectively matched the broader population of airports (within the defined geographic and operational scope) on a predetermined set of balancing factors (e.g., airport size, traffic volume, region). The specific balancing factors used in the NES are illustrated in Figure 2.

A similar approach could be taken for the selection of sites with UAM and sUAS operations, with the specific balancing factors selected as part of the study design once UAM is operational.

Balancing Factor	Description of Selection Variables
FAA Region	Proportion of airports in each of eight FAA regions in the contiguous US(1)
Average Daily Temperature	Proportion of airports with average daily temperature above 70 degrees F
	Proportion of airports with average daily temperature below 55 degrees F
Percent of DNL Nighttime Flight Operations	Proportion of airports with 20 percent DNL nighttime operations(2)
Average Daily Flight Operations	Proportion of airports with more than 300 average daily flight operations(3)
Aircraft Fleet Mix Ratio	Proportion of airports with a fleet mix ratio of commuter to large jet aircraft flight operations exceeding 1(4)
Population within 5 Miles	Proportion of airports with at least 230,000 people living within 5 miles of the airport(5)

Notes:

(1) The FAA has nine regions but only eight in the contiguous US.

(2) DNL nighttime is 10:00 p.m. to 6:59 a.m.; 20 percent was the originally calculated median percentages of nighttime operations, discovered later to have been in error, see text below and Appendix C for further detail .

(3) Three hundred flight operations was a rounding of the median number of daily flight operations across the 95 airports, 270.

(4) Large jet aircraft defined as jet-engine aircraft weighing more than 41,000 pounds, such as the B737, A320, B757, B747; Commuter aircraft are all non-jet aircraft, such as the ATR-42, SF-340 and general aviation aircraft, along with regional and business jet aircraft, such as the Canadair Regional Jet and Learjet.

(5) The mean population within 5 miles of the airport, 230,000, was selected as the dividing point (instead of the median) because it ensured that the airports with the largest population affected were represented in the sample proportionately to their representation in the population of 95 airports.

Figure 2 Balancing factors used for the selection of airports in the NES

4.3.4.2 Respondent selection

The first step for respondent selection is to define a lower bound of noise exposure for sampling. This threshold should be determined based on the best available evidence or national guidance regarding the onset of adverse impacts from UAM and sUAS noise exposure.

Stratified random sampling can then be used to select addresses across a range of noise exposure bands. Stratified random sampling involves dividing the study population into distinct noise exposure bands (strata) and then randomly selecting an equal or predetermined number of addresses within each stratum. This approach ensures that there are enough responses across all exposure bands to derive a statistically robust dose-response relationship.

The required number of households to contact within each stratum can then be calculated based on the target number of completed surveys and an assumed survey response rate (e.g. if 100 respondents are targeted for a given noise exposure band and the assumed response rate is 40%, then 250 addresses would be contacted in that band). Should there be insufficient eligible addresses within a particular noise exposure band to meet the target, these shortfalls can be reallocated proportionally to other strata.

It should be noted that this sampling approach will require noise exposure contours to be available for each site/community prior to the survey.

4.4 Metrics

The 'Percent Highly Annoyed' (%HA) metric quantifies the proportion of respondents in a survey who report high levels of annoyance due to noise exposure. This percentile-based metric was originally developed by Schultz[96] as part of his seminal work synthesizing social surveys on noise annoyance. Schultz defined 'highly annoyed' as those expressing annoyance in the upper 28% of an 11-point numerical annoyance scale (scores of 8, 9, or 10). For surveys employing a five-point verbal scale, 'highly annoyed' is typically defined as the top two response categories (e.g. 'Very' and 'Extremely annoyed').

The use of %HA was motivated by observations of better correlation between noise exposure and annoyance at higher annoyance levels and its practical utility for policy-making compared to mean or median annoyance scores. %HA remains a widely adopted and interpretable metric in community noise studies globally. It is the basis for WHO guidance, and it is commonly used in impact assessments for new infrastructure projects to estimate the health impacts associated with changes in noise exposure.

4.4.1 Alternative response metrics and qualitative data

Annoyance from UAM and sUAS noise may depend on the degree of interference with daily life activities such as speech communication, relaxation, sleeping, tasks requiring concentration, and listening to the radio or TV, etc. It would be beneficial to have self-report ratings for activity disturbance within the questionnaire.

As the primary aim of the study is to develop a dose-response relationship, the data collection methods and metrics discussed so far in this report have been necessarily quantitative in nature. However, within the questionnaire, open questions could be included to elicit more information about 'how' people respond to UAM and sUAS noise and 'why' respondents give a particular rating of annoyance.

The value of qualitative data has long been recognized within the social sciences, being seen as a prerequisite for good quality quantitative research[97] and as a beneficial counterpart for quantitative research[98]. Qualitative, open-ended questions can therefore be used to interpret the dose-response relationship and potentially further understandings of any outliers (e.g. a respondent with high annoyance ratings and low noise exposure). This mixed-methods approach will provide a more holistic view of annoyance, which is particularly important for emerging noise sources like UAM and sUAS.

4.4.2 Laboratory studies

Several planned laboratory studies outlined in the scoping document will directly support the design and analysis of this study. For example, comparative tests of UAM and sUAS noise can inform how these sources are defined in the questionnaire. A study investigating the effect of the number of operations on annoyance may help guide

[96] Schultz, T. J. (1978). Synthesis of social surveys on noise annoyance. The Journal of the Acoustical Society of America, 64, 377-405.

[97] Pope, C., & Mays, N. (1995) Qualitative Research: Reaching the parts other methods cannot reach: an introduction to qualitative methods in health and health services research. British Medical Journal, 311, pp. 42-45

[98] Moran-Ellis, J., Alexander, V., Cronin, A., Dickinson, M., Fielding, J., Sleney, J., & Thomas, H. (2006) Triangulation and integration: processes, claims and implications. Qualitative Research, 6(1), pp. 45-59

the selection of appropriate exposure metrics. Similarly, research into the influence of ambient sound conditions could inform site selection and serve as a balancing factor in the sampling strategy (see section 4.3.4.1)

While these studies are primarily hypothesis-driven and rooted in a positivist framework, the broader study would benefit from complementary exploratory work to better understand how people perceive and categorize UAM noise. One useful approach would be a free sorting and category elicitation task[99], in which participants group UAM and sUAS sounds based on perceived similarity and provide labels for each group. This method can reveal natural perceptual categories and inform how source definitions are framed in the questionnaire. Hierarchical clustering can be used to identify the number of perceptual groups, while multidimensional scaling (MDS) can help uncover the underlying perceptual dimensions.

4.4.3 Pilot testing and early field test opportunities

Given the novelty of the technology and uncertainty around modeling tools (see section 3.2) and definitions of UAM for question construction (see section 4.3.3.2), early pilot testing of the proposed approach will be vital. Pilot testing would allow the validation and refinement of both the noise modeling tools discussed in section 3.2 and the survey questionnaire. This pilot testing could form part of the three-year lead-in to the full FAA-led survey, allowing the findings of the pilot test to be incorporated into the methodology for the full FAA-led survey.

Early UAM demonstrations could be leveraged for the early testing of tools. For example, in upcoming events (such as the 2025 Osaka World Expo or the 2028 Los Angeles Olympics where air taxi demonstrations are planned), small-scale studies could be conducted to test the proposed modeling and response collection approaches. It should be acknowledged that any data gathered during early testing is not likely to be representative of long-term steady state response. It is also likely there will be significant community engagement and publicity in the run up to these events that could bias the community response. However, these early demonstration events provide a valuable opportunity to test the emerging noise modeling and response collection methodologies.

[99] Parizet, E., & Koehl, V. (2012). Application of free sorting tasks to sound quality experiments. Applied Acoustics, 73(1), 61-65.

5. Other Activities

5.1 Aims and objectives

A successful project relies on weaving several foundational elements, outlined below and described more thoroughly in this section:

- Effective project coordination ensures that stakeholders, technical teams, tasks and timelines are aligned, reducing misunderstandings, streamlining workflows and clarifying responsibilities for a smooth project execution. This is described in section 5.2.
- The development of guidance and standards provides a consistent framework that supports quality control, regulatory compliance, and interoperability across project components. To translate lessons learned into standards helps to streamline processes and reduces ambiguity during implementation. This is described in section 5.3.
- Community engagement will need to be limited in other not to influence the annoyance responses to the survey. However, engagement with local jurisdictions, international bodies and key stakeholders will be very important. An effective communication plan outlining what to communicate, what not to communicate and creating/aligning reactive statements in case something does not happen according to plan is essential to mitigate risks. This is outlined in section 5.4.
- Technical reviews are a means to promote quality control, validate the scope, monitor and control project tasks and identify and manage risks. They promote excellence and proper requirement elicitation and strengthen the project outcomes. They are described in section 5.5.
- Data protection principles are outlined in section 5.6.

These foundational elements are described in the subsections below.

5.2 Coordination

We propose a coordinated, ecosystemic approach that considers the complex interconnections between people, the environment, systems, and long-term impacts, helping to ensure positive and lasting outcomes. Instead of focusing narrowly on isolated results, it integrates multiple layers to develop sustainable and adaptive solutions. Based on our experience[100], the following aspects should be considered.

5.2.1 Stakeholder mapping and requirements elicitation

A stakeholder is "*an individual, group, or organization who may affect, be affected by, or perceive itself to be affected by a decision, activity, or outcome of the project*."[101] In the context of environmental matters, this definition is closely aligned with the definition of "interest party" as per ISO 14001:2015[102], that is defined as "*a person or organization that can affect, be affected by, or perceive itself to be affected by the environmental performance of an organization.*"

[100] CAELUS reports available at https://www.agsairports.co.uk/drones

[101] Project Management Institute (PMI), 2017. A Guide to the Project Management Body of Knowledge (PMBOK® Guide). 6th ed. Newtown Square, PA: Project Management Institute.

[102] ISO/DIS 14001 (2014). Environmental management system: Requirements with guidance for use. Geneva, Switzerland: International Organization for Standardization

Examples of stakeholders that will need to be engaged with as part of the project include:

- Original Equipment Manufacturers (OEMs) that will be flying and providing NPD data
- U.S. Department of Transportation Volpe National Transportation Systems Center (DoT Volpe Center), responsible for overseeing the dose estimation analysis and noise monitoring
- entity undertaking the noise modeling if DoT Volpe Center has a contractor or consultant on board to undertake this activity
- entity responsible for managing the survey (post/ online/ telephone)
- entity responsible for the data management
- National Aeronautics and Space Administration (NASA)
- Federal Aviation Administration (FAA) Office of Environment and Energy (AEE-100): Survey lead, manages and owns some assets, including the AEDT
- Non-Governmental Organizations (NGOs)
- International Civil Aviation Organization (ICAO), especially WG1 and WG2
- The Federal Interagency Committee on Aviation Noise (FICAN) - Forum to coordinate with Department of Defense, Department of the Interior, Department of Transportation, Environmental Protection Agency, NASA and Department of Housing and Urban Development
- standard making bodies to support tool/method development such as SAE and BSI
- Local Jurisdictions
- Government

Questions to consider when mapping stakeholders include:

- What motivates them?
- How can you influence them?
- Which information would they like to receive?
- How would they like to receive it?
- What information do we require from them?
- What dependencies are they responsible for?

While often a preliminary stakeholder mapping exercise is undertaken in projects, the coordination team often fails to rigorously validate stakeholder identities or systematically elicit their requirements. This often results in weak stakeholder engagement and, ultimately, failure to secure a social license for the project to operate.

Commonly used in software development, system engineering and project management, requirements elicitation is defined in ISO/IEC/IEEE 29148 as "*the process of seeking, uncovering, acquiring, and elaborating requirements for computer-based systems.*" It is used when a team needs to communicate and engage with a variety of stakeholders, for numerous purposes regarding many aspects of the project. It translates stakeholder needs into accurate and actionable requirements. The process of requirements elicitation is composed of elicitation, analysis, specification, validation, and management[103]. It is well known that a poor requirement elicitation will almost certainly guarantee that the final project is a complete failure[104] [105] [106].

Techniques to properly gather stakeholder requirements include documentation analysis, conducting interviews, focus groups, capturing data through surveys or questionnaires, requirement workshops and, use cases. Once these requirements have been properly identified and needs and expectations are well understood, they can be incorporated into the planning, design, and implementation of the project.

The validation is defined in ISO 29148 as "*the set of activities ensuring and gaining confidence that a system is able to accomplish its intended use, goals and objectives. The right system has been built.*" The validation process is described in the same standard.

The methodology applied in the validation exercise must include:

- How will the requirements be validated?
- Who is responsible for the validation of the requirement?
- When will the validation take place?
- What is the location of the validation (e.g. flightpath, at the residences, etc.)?

Requirements should then be managed throughout the project cycle, with special attention given to aspects such as policy and regulation, usability, performance, interface, and design.

5.2.2 US Government Agencies

Throughout the inception and development of the study, engagement with federal and local government agencies will be important in ensuring consistency of approach and compatibility with policy and policy makers in relevant departments. Studies should also be coordinated, as far as is practicable, with relevant national and local standards and guidelines. This should include the governmental bodies identified in section 5.2.1. The US Government Agencies are well defined in the scoping document.

5.2.3 International coordination

In line with the scoping document, we recommend that international coordination is undertaken with:

- The International Civil Aviation Organization (ICAO) Committee on Aviation Environmental Protection (CAEP) Working Group 1 (noise) and Working Group 2 (Airports and Operations) – since harmonization is one of the core principles of these groups and they are an obvious international authority in terms of governance
- Other regulatory agencies, including U.K. CAA, EASA and Civil Aviation Safety Authority (CASA)

While we acknowledge the importance of engaging with other research centers and AAM manufacturers, many of these entities are already coordinating closely with their respective local regulatory agencies. Additionally,

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[103] Pacheco, C. and Garcia, I., 2012. A systematic literature review of stakeholder identification methods in requirements elicitation. Journal of Systems and Software, 85(9), pp.2171-2181.

[104] Pacheco, C. and Garcia, I., 2012. A systematic literature review of stakeholder identification methods in requirements elicitation. Journal of Systems and Software, 85(9), pp.2171-2181.

[105] Clancy, T. 1995. The chaos report. West Yarmouth, MA: The Standish Group.

[106] Khan, A., Waris, M., Panigrahi, S., Sajid, M.R. and Rana, F., 2021. Improving the performance of public sector infrastructure projects: Role of project governance and stakeholder management. Journal of Management in Engineering, 37(2), p.04020112.

manufacturers such as Archer, Eve Air Mobility, and Joby are actively participating at the ICAO level. Engagement with these stakeholders will not be overlooked; rather, it will naturally emerge through the ongoing collaboration with ICAO and relevant regulatory bodies.

However, effective international coordination within the scientific community is essential to ensure that survey methods, noise modeling approaches, and metrics are harmonized globally, enabling future meta-analyses across different countries. We propose that an international technical working group / steering committee is set up specifically for this task or that this is done through the UAM Noise Working Group (UNWG). Although different and well-established technical working groups are cited in this document, each of these groups' work has an established perspective and for the current task it might be beneficial to bring together different perspectives and a fresh outlook. This is described in section 5.5.

Engagement through the UNWG has already been fruitful as evidenced in the generation of guidance documents like the measurement protocol (subgroup 2) and ground and flight testing (subgroups 3 and 4).

5.2.4 Local Coordination

Even though this is not part of the original scoping document, we recommend undertaking coordination with local jurisdictions. Given that UAM aircraft operation is not restricted to airports, local jurisdictions become key stakeholders and are one of the first to be affected by noise complaints, even though roles and responsibilities of Federal and local jurisdictions are still not clearly defined.

Promoting early engagement and educating members of the local jurisdictions significantly reduces risks. A common mistake is not to engage and "test their reaction" or in the case of the task at hand, where confidentiality is required to undertake the study, not to inform them or limit the amount of information provided.

In our experience, the purpose of the study and its stages must be clearly laid out in an engagement plan for the local jurisdictions. The need for confidentiality must be explained, as well as the impact in case confidentiality is not taken seriously. It is important to consider that sometimes the knowledge (full or in part) of the study will get to the public domain and stakeholders need to prepare in case this happens. Stakeholders (especially the local jurisdiction) need to be briefed with a reactive message in case something goes wrong such that they need to issue a statement to the press. This can make the difference for a project to be successful or a complete failure.

5.3 Standards and guidance development

We understand that the scoping document focuses on standards and guidance in development applied to the tasks to be carried out in the United States and with appropriate survey methods to the extent they might differ for this purpose (such as ICBEN). However, in line with the international coordination task defined in section 5.2.3, we also understand that there might be standards and guidance being developed outside the United States that will impact the harmonization and transferability of methods and metrics for a meta-analysis.

Consequently, we broadened the text of this section to encapsulate the process of standardization across the globe. In the United Kingdon, for example, the British Standards Institution (BSI) is actively involved with the Future Flight Challenge, a UK government-backed program aimed at developing new aviation technologies such as eVTOLs and UAS. Specifically, BSI is leading the Future Flight Standards Programme, which focuses on creating standards to enable the safe and efficient integration of these new technologies. This collaboration helps accelerate the development and adoption of innovative aviation solutions.

BSI has developed a standards roadmap to support the growth and industrialization of Future Flight in the UK[107]. The roadmap is designed to help industry stakeholders navigate the evolving regulatory and standards landscape, ensuring the safe and scalable integration of these emerging aviation technologies. It is structured around key

[107] https://future-flight.bsigroup.com/roadmap/

themes, providing a clear framework for standardization activities. A UAS pathway has also been mapped out for specific operational needs of medical cargo delivery and infrastructure inspection.

5.3.1 Standardization

Standardization is the process of creating, issuing and implementing standards. A standard is a document, established by consensus and approved by a recognized body. It provides rules, guidelines, or characteristics for activities or their results so that they can be repeated. The aim is to achieve the greatest degree of order in a given context.

Standards are produced by national standards organizations (such as the American National Standards Institute – ANSI and British Standards Institute - BSI) and internationally applicable standards by ISO – International Organization for Standardization. Detailed information on due process requirements, including an annex describing procedures for the development of a provisional standard is published by ANSI[108]

Standards should provide a reliable basis for people to share the same expectations about a product or service, which helps to:

- facilitate trade
- provide a framework for achieving economies, efficiencies, and interoperability
- enhance consumer protection and confidence

Standards can be supported through measurement, testing, certification, and accreditation.

The underpinning principles to standards are globally similar:

- Respond to a need in the market: standards organizations do not decide when to develop a new standard but respond to requests from industry or other stakeholders, such as consumer groups.
- Based on national or global expert opinion: standards are developed by technical committees of experts who negotiate all aspects of the standard, including its scope, key definitions, and content.
- Developed through a multi-stakeholder process: technical committees are made up of experts from the relevant industry and may also include representatives of consumer associations, academics, NGOs, and local or national government.
- Based on consensus: technical committees aim to achieve a consensus-based outcome, taking into account contributions from all stakeholders and seeking wider opinion through publication of draft standards for public comment.

Requests received by standardization organizations are reviewed by standardization experts who consider whether the proposal is suitable for a standard. Applicants should consider:

- Whether the proposal relates to a product, service or process
- Why is the standard necessary
- For which industry(ies) is it relevant and specifically, who would use the standard
- Which trade associations or industry bodies should be involved in its development

[108] ANSI Essential Requirements: Due process requirements for American National Standards. January 2025. https://share.ansi.org/Shared%20Documents/About%20ANSI/Current_Versions_Proc_Docs_for_Website/ER_Pro_current.pdf

- Whether there already exist any relevant standards or relevant good practice guidance within the industry
- Whether there are any Intellectual Property Rights (IPR) or patent related issues related to this idea.

Once the suitability of the proposal is confirmed, the standards organization may be required to create an internal business case to have the standard developed, after which, the chair and technical committee members need to be agreed and convened. All members would need to provide supporting evidence and possibly a sponsor, to validate their professional suitability to be a contributor. The general process is illustrated in Figure 3.

Figure 3 Standard development process stages

5.3.2 BSI and SAE

Both BSI and SAE develop and publish standards to improve quality, safety, interoperability, and efficiency. They are both consensus-based institutions and welcome input from industry, academia, and government. Having international reach, both BSI and SAE participate in ISO/IEC activities and provide support for compliance by offering tools and training to help organizations comply with standards in aerospace, though at different levels and scopes. While BSI is a founding member of ISO and national standards body for the UK (and represents UK at ISO, IEC), SAE contributes with technical content to ISO/SAE standards but not a national standards body. Also, while BSI provides ISO certification and audits, SAE does not provide certification, but is a standards developer and training body, not a certifying body. Given that both SAE and BSI are currently investigating the need for developing standards for UAM, we recommend that activities of both institutions be monitored, and other relevant global institutions be identified in the requirements elicitation.

The SAE A-21 committee is supervising a series of technical standards (ARP) and guidance (AIR), implemented in many prediction tools such as AEDT or defining measurement methods. These standards were initially developed for conventional aircraft and rotorcraft, and discussions are currently occurring around their applicability for UAM. As part of its bi-annual meetings, the SAE A-21 committee invites university, industrial, and governmental institutions to present their studies to inform the need of developing future standards. These bi-annual meetings provide a platform of international experts to review and discuss, in particular, the challenges of undertaking noise measurements of UAM.

The guidance on noise annoyance questions and rating scales in TS ISO 15666 was developed through the International Commission on the Biological Effects of Noise (ICBEN) (see section 4.3.3.1). ICBEN organizes an international congress every three years, which would provide an ideal forum to present the development of the survey methodology and questionnaire to international experts and the wider scientific community. The project should engage with ICBEN Team 6 (Community response to noise and annoyance), particularly on any aspects of the survey that deviate from the guidance in TS ISO 15666.

5.4 Community engagement

We understand that community engagement will need to be limited to minimize influence of the annoyance responses to the survey. For the same reason, we recommend that research is undertaken to understand what (if any) community engagement has happened prior to UAM being introduced.

We consider that the following engagement will be needed:

- Engagement with key stakeholders, described in section 5.2.1
- Engagement with local jurisdictions, described in section 5.2.2

- Engagement with international bodies, described in section 5.2.3

This project will only thrive if stakeholders are able to engage in fruitful and collaborative discussions. Aircraft manufacturers, airlines, infrastructure, air traffic control services, governments, and policy makers are some of the entities involved in the process.

A rigorous stakeholder engagement is essential to:

- Facilitate dialogue on implications for public health and wellbeing (from a noise perspective)
- Increase transparency on how stakeholders could be affected by a proposed development (or novel noise sources)
- Ensure proposals are inclusive and accessible
- Support data driven decision making
- Help identify stakeholders' needs and concerns
- Build trust amongst the entities through impartial advice and integrity

When undertaking any engagement, it is important to focus on independent technical advice and not communicating an opinion; to listen as much as talk; and to make every effort to achieve consensus based on data and science. Proper stakeholder mapping, requirements elicitation, communication plan, and independent technical advice are essential for the success of this project.

5.4.1 Communication plan

A communication plan must be created. Some aspects to be considered include:

- Definition of key messages
- Advice for local jurisdictions and key stakeholders on what not to say
- Preparation of reactive media statements, prepared for each activity
- Preparation of proactive social media statements so that the community is not alarmed
- Preparation of reactive statements in case of crisis communications being needed
- Anticipation of what film footage/photographs will be needed for future engagement/press releases
- Consideration of the use of web platforms to maximize engagement if needed at later stages of the project, e.g. https://caelus.commonplace.is/
- Design of a list of Frequently Asked Questions (FAQ)

5.5 Technical reviews

To ensure scientific robustness and credibility, an international steering committee should be established to oversee the development of the survey methods, noise modeling approaches, and metrics. This committee would be responsible for ensuring that the methods used are appropriate for deriving a nationally-representative dose-response relationship and that the survey design does not introduce bias. When applicable, the steering committee should also see that those techniques and/or data are harmonized globally, enabling future meta-analyses across different countries.

In particular, the questionnaire and survey methodology should undergo rigorous peer review. This includes evaluating the clarity of source definitions, the appropriateness of the annoyance scales, and the inclusion of relevant non-acoustic factors. The review should also assess whether the survey mode and sampling strategy are likely to yield representative and reliable data.

Precedents from previous studies highlight the importance of independent review. For example, in the National Environmental Survey (NES), the Federal Interagency Committee on Aviation Noise (FICAN) reviewed the methodology used to select the 20 surveyed airports. The Bureau of Transportation Statistics (BTS) also reviewed the statistical methods. An Expert Review Panel was convened, comprising international professionals in noise dose-response research. This panel provided independent, third-party review of the survey design, noise modeling, regression analysis, supplemental analyses, and the development of the national dose-response curve. Panel members represented private industry, a research division of the U.S. Department of Transportation, and two European scientific organizations. In addition, the survey methods and findings were presented at international conferences.

5.6 Data Protection Principles

The United States does not have a single, comprehensive federal equivalent to the EU's General Data Protection Regulation (GDPR). Instead, it follows a sectoral approach with data privacy laws varying by industry and state. Growing state-level regulations are inspired by these GDPR principles. When working with American federal agencies, the compliance standard for data governance is defined in Office of Management and Budget (OMB) policies and circulars[109] (such as A-130[110] and A-11[111]). The OMB is also responsible for implementing the Paperwork Reduction Act[112] (PRA). They issue guidance and approve or reject agency requests to collect information from the public.

The PRA requires federal agencies to:

- Minimize the paperwork burden on individuals, small businesses, and others
- Justify information collections
- Obtain OMB approval (via the Office of Information and Regulatory Affairs, OIRA) before collecting information from the public
- Display a valid OMB control number on approved forms or surveys

In any case, following the seven data protection principles outlined in sections 5.6.2 to 5.6.8 below promotes good governance and operational efficiency, reduces risks, builds trust, and demonstrates international alignment. Robust best practices are a fundamental building block for good data protection practice and include:

- Providing a clear privacy notice before survey participation[113]
- Avoiding the collection of unnecessary personal identifiers (and if collecting identifiable information, obtaining explicit consent)
- Allowing participants to opt out or request deletion if applicable
- Documenting the process considering:
  - Where did you get the data from?

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[109] Circulars | OMB | The White House

[110] OMB Circular A-130, Managing Information as a Strategic Resource (2016)

[111] OMB Circular A-11, Preparation, submission and Execution of the Budget (2024)

[112] The Paperwork Reduction Act (PRA) is codified under 44 U.S.C. §§3501-3521. It was initially enacted in 1980 (Public Law 96-511) and amended in 1995 (Public Law 104-13).

[113] Example: https://www.commonplace.is/privacy-policy

- How was it obtained?
- What steps did you take to ensure it was accurate and up to date?
- What do you intend to use the data for?
- How long do you intend to use it for?
- What will you do with data you no longer need?

Personal data is defined in section 5.6.1 and following the seven data protection principles outlined in sections 5.6.2 to 5.6.8.

5.6.1 Personal data

Personal data only includes information relating to a person who can be identified directly from the information in question, or can be indirectly identified from that information in combination with other information. Examples of identifiers include identification number, location data, and an online identifier (IP addresses and cookie identifiers).

It is important to remember that even though pseudonymized data can help reduce privacy risks by making it more difficult to identify individuals, it is still personal data. Information about companies or public authorities is not personal data.

5.6.2 Principle of Lawfulness, Fairness, and Transparency

Identify a valid legal basis and comply with all applicable laws of the US State where the data is going to be collected (Lawfulness). Avoid processing that is unexpected, harmful, or misleading to individuals (Fairness). Be open and honest from the outset about how personal data will be used (Transparency).

5.6.3 Principle of purpose limitation

Clearly define why personal data is being collected before collection begins. Document those purposes (e.g. in processing records) and communicate them in privacy notices.

If the data is considered for a later new purpose, only proceed if:

- The new purpose is compatible with the original
- Fresh consent is obtained
- There is a legal obligation or public interest allowing the new use

5.6.4 Principle of data minimization

Data minimization means collecting the minimum amount of personal data needed to deliver an individual element of your service. Practical implications include:

- Collect only what is necessary: ensure each data point serves a clear, documented purpose
- Segment by function: for multi-feature services, gather only the data needed for each feature
- Avoid over-collection: do not bundle multiple data uses under one collection, especially for optional enhancements
- Retention discipline: keep data only as long as needed; delete once obsolete

5.6.5 Principle of accuracy

Take all reasonable steps to ensure the personal data you hold is not incorrect or misleading as to any matter of fact. Practical implications include:

- Correct or erase inaccurate information promptly
- Treat any challenges from individuals regarding their data seriously and investigate them thoroughly

5.6.6 Principle of storage limitation

Personal data should be kept in a form which permits identification of data subjects for no longer than is necessary for the purposes for which the personal data are processed. Personal data may be stored for longer periods if the data will be processed solely for archiving purposes in the public interest, scientific, or historical research purposes or statistical purposes, subject to implementation of the appropriate technical and organizational measures required to safeguard the rights and freedoms of the data subject. In practical terms, this means:

- Specify how long personal data is required for the purpose(s) it was collected
- Set and implement retention periods, destroying or anonymizing data when it is no longer needed

5.6.7 Principle of integrity and confidentiality (security)

Appropriate security measures must be in place to protect the personal data held, which means ensuring that:

- Personal data is processed in a manner ensuring appropriate security, including protection against unauthorized or unlawful processing, and accidental loss, destruction, or damage,
- Security is achieved through appropriate technical and organizational measures

5.6.8 Principle of accountability

The accountability principle requires that responsibility is taken for personal data and how the other principles are complied with. Appropriate measures and records must be in place to be able to demonstrate actions taken.

6. Gaps Identified in Scoping Document

The review of the scoping document also identified the following missing activities.

- In the dose-related section, the following gaps were identified:
  - Sensitivity testing to understand the level of complexity needed to represent specific scenarios, and consequently which modeling technique(s) is needed to represent the physics in a way that the model is complex enough to represent the real scenario but simple enough to be tackled in the required timescales with available hardware and software.
  - The use of IoT sensor networks for wide scale noise monitoring
- In the response-related section, the following gaps were identified:
  - The inclusion of source-specific annoyance questions, alongside the general annoyance questions
  - Questions on annoyance responses at different times of day
  - Reference to ISO TS 15666, which contains the most up to date ICBEN guidance for the wording of response questions and scales
  - An activity to define sources, making sure the definitions are understandable by the public
  - Consideration of non-acoustic factors and data on activity disturbance, including self-reported sleep disturbance
  - Inclusion of open qualitative questions to provide context to the quantitative annoyance responses
  - Inclusion of any significant pilot testing component
  - Consideration for exploratory laboratory studies, to complement the laboratory studies proposed in the scoping document and to feed into the definition of sources
- In the other activities section, the following gaps were identified:
  - A methodology for stakeholder mapping and requirements elicitation to be included from the first month of the project
  - Coordination with local jurisdictions and the development of a communication and engagement plan to reduce risks
  - Consideration of standards and guidance being developed outside the United States to promote the harmonization and transferability of methods and metrics for a meta-analysis
  - Consideration of data protection principles should be included as we understand this significantly minimizes risks

7. Preferred Approach

Our recommended approach to the community noise study is a cross-sectional survey of a nationally-representative sample of communities, supplemented by targeted longitudinal studies in a subset of those communities. This design enables the derivation of a nationally-representative dose-response relationship while also capturing how annoyance evolves over time after the introduction of UAM operations. The cross-sectional survey should be conducted only after UAM vehicles have been operational in the selected communities for at least 12 months. The longitudinal studies could begin shortly after UAM introduction, with follow-up surveys every six to 12 months.

7.1 Three-year lead in period

The three-year planning phase should focus on developing and validating tools for estimating noise exposure, designing and testing the survey instrument, and coordinating with relevant stakeholders. Given the technical challenges in modeling and potential difficulties in defining UAM sources in the questionnaire, a major focus of the planning phase should be a pilot test to allow the refinement of tools and methods before the full survey.

The first phase of the three-year lead in will involve setting up stakeholder groups, defining objectives and deliverables, identifying workstream leads, and holding stakeholder engagement workshops to elicit project requirements. Suitable sites for model validation and pilot testing activities should be identified in this phase.

The second phase should be split into dose and response workstreams to develop and validate the necessary noise modeling tools, questionnaire, and study design. Arup's preferred approach to issues related to dose and response related tools are detailed in sections 7.2 and 7.2 respectively. A third workstream on engagement should also be set up to obtain the necessary data for noise modeling (i.e. ADS-B operation data and NPD data from OEMs), review state data laws, develop a data impact assessment, and engage with local jurisdictions for the selected pilot testing site.

The third phase will involve a 12-month pilot study to test the modeling tools, survey methodology, and proposed statistical analysis methods. A six-month refinement period should follow to allow the tools and methodology to be refined considering the findings of the pilot testing, before handover to the FAA for the full community noise study.

7.2 Dose related activities

Developing modeling tools for UAM noise exposure is a key challenge due to the current level of technical maturity in UAM modeling compared to conventional aviation. Given the scale of dose data required (likely to be predictions at thousands of locations), an integrated tool such as AEDT is preferred for its scalability. The program should include provisions for model validation and calibration, which may require long term noise monitoring.

Input data requirements will depend on the final modeling approach. Measured source noise data is preferred as the basis for the development of NPD curves, though it may not be available for all vehicle types and operational modes. In such cases, validated prediction methods can be used. When requesting NPD data from OEMs, a cost-efficient strategy should be adopted to minimize burden, such as limiting the number of aircraft configurations and operational conditions.

Data on UAM operations within each study area will be required, including numbers of operations, vehicle type, and ground track data. A large enough sample of data will be required to establish typical routes and dispersion patterns over the 12-month survey timeframe for each site. This data will also provide insights into flight speed and configuration variability relative to standard procedures, allowing site-specific models to be developed.

Baseline ambient noise levels may be required as part of the dose-response analysis. It will not be feasible to measure a baseline at each survey location. It is therefore likely the results of national noise mapping or tools such as BRRC's AMBIENT model will be required. These models should be verified/validated for each survey site.

Due to UAM and sUAS operating within the urban environment, sensitivity tests should compare AEDT with models that account for complex propagation effects such as building screening and water. If significant differences are found, consideration should be given to modeling the most sensitive areas using these tools, for example around vertiports.

It is recommended that the primary dose-response relationship is formulated using L_{Aeq}-based metrics to support international comparison and alignment with national aviation policy. Event-based metrics such as L_{Amax} and N_x should also be explored. While full-scale modeling of psychoacoustic metrics may not be feasible, their inclusion in a subset of sites would provide valuable insights into the efficacy of these metrics to describe annoyance.

7.3 Response related activities

In-person questionnaires would be the gold standard data collection method for the social survey. As well as high coverage and response rate, the main advantage of an in-person community survey on UAM noise would be that the interviewer can clarify any ambiguities or misunderstandings around the definitions of UAM and sUAS used in the questionnaire. However, it is recognized that given the scale of surveys required, in-person surveys are likely to be cost prohibitive.

Postal surveys with follow-up telephone interviews, an approach that was used successfully in the NES, are likely to be the most pragmatic approach. The main annoyance question(s) can be asked in the postal survey, with more detailed follow up questions on contextual, attitudinal, and situational factors asked in the follow-up telephone interview. However, the definitions of UAM and sUAS used in the postal survey will need to be rigorously tested to ensure they are understandable to the public.

The questionnaire should be framed as a neighborhood satisfaction/neighborhood environment survey to avoid biasing responses. The wording of the annoyance questions and rating scales should follow the guidance in ISO/TS 15666. Both the five-point semantic and 11-point numerical scales should be included in the questionnaire. This would ensure the greatest compatibility for combination with other international studies for future meta-analyses.

The timescale over which the respondent is being asked to rate annoyance should be clearly defined. ISO/TS 15666 asks the respondent to consider the last "*12 months or so.*" There is flexibility in the standard, so this can be modified if asking about annoyance at different times of day or if UAM has not been operational for 12 months (i.e. in the case of a longitudinal study).

The main annoyance question should address combined UAM and sUAS operations, followed by items targeting specific sources (e.g. vertiports, overflights, vehicle types) and at different times of day (i.e. day/evening/night). Additional questions should capture socio-demographic, attitudinal, and situational/contextual factors. A thorough literature review should be conducted during the design of the questionnaire to determine which of these factors should be measured. Examples of these factors could include:

- Attitudinal factors: perceived necessity or social value of UAM, fear of the source, noise sensitivity, and expectations about future noise levels.
- Situational factors: residential area type, property characteristics, visibility of UAM operations, neighborhood satisfaction, building height, and time spent at home.
- Socio-demographic factors: age, gender, ethnicity, employment status, home ownership, household size, and daily presence at home.

Annoyance due to UAM noise may also depend on interference with daily activities such as communication, relaxation, sleeping, home working, watching TV, etc. It is recommended that responses to the degree to which these activities are disturbed are also collected. Qualitative data should be collected alongside the quantitative response data. This would provide more information about ‘how’ people respond to UAM and sUAS noise and ‘why’ respondents give a particular rating of annoyance. If a mixed-mode approach is taken, these additional factors and qualitative data could be collected via the follow-up telephone interviews.

Following established conventions and guidance in ISO/TS 15666, the percentage highly annoyed category should be created by combining categories ‘very’ and ‘extremely’ on the five-point semantic scale and 8, 9, 10 (the top three categories) on the 11-point numerical scale.

Dose-response relationships can be modeled using ordinal logit, ordinal probit with fixed thresholds, or multilevel grouped regression. The latter is preferred, as it models the full response distribution as a function of noise dose, allows calculation of any summary response metric (i.e. %HA, %A, %SA), and can account for variability across sites and individuals. The influence of additional non-acoustic factors should be explored by including them as variables in the regression model.

Site selection should aim for national representativeness of UAM-operating areas. The balancing factor approach used in the NES provides a robust framework. Once sites are selected, stratified random sampling within noise exposure bands should be used to identify survey participants. This requires prior noise modeling to generate contours for sampling.

7.4 Other activities

Effective project coordination ensures that stakeholders, technical teams, tasks, and timelines are aligned, reducing misunderstandings, streamlining workflows, and clarifying responsibilities for a smooth project execution. Our recommendations for effective project coordination are as follows.

Stakeholders should be mapped, and the process of requirements elicitation starts in Phase 1. Stakeholders should be mapped in the first two months of the project plan with special care for the ones already identified in section 5.2.1. Stakeholders and requirements should be validated in the first stakeholder workshop, planned for the third month. The process of requirements elicitation should be based on the standard ISO/IEC/IEEE 29148 and be composed of elicitation, analysis, specifications, and management. Requirements should then be managed throughout the project cycle, with special attention given to aspects such as policy and regulation, usability, performance, interface, and design

We recommend that primary international coordination be undertaken through ICAO WG1 and WG2 and regulatory agencies. An international technical working group should be set up specifically for ensuring that survey methods, noise modeling approaches, and metrics are harmonized globally, enabling future meta-analyses across different countries – and a fresh perspective. One outcome of this task will be understanding of recently developed standards across the globe and standard harmonization.

It is highly recommended that an engagement plan with the local jurisdictions be put in place. It should clearly outline the purpose of the study and its stages. The need for confidentiality should be explained as well as the impact in case confidentiality is not taken seriously. A communication plan should be created and monitored.

The development of guidance and standards provides a consistent framework that supports quality control, regulatory compliance, and interoperability across project components. Translating lessons learned into standards helps to streamline processes and reduces ambiguity during implementation. We recommend that standards and guidance being developed outside the United States should also be considered in the requirements elicitation phase, as they will impact the harmonization and transferability of methods and metrics required for a meta-analysis. Institutions such as SAE and BSI should be included, and others might be identified as a result of the elicitation.

Community engagement will need to be limited to minimize any influence of the annoyance responses to the survey. However, engagement with local jurisdictions, international bodies, and key stakeholders will be very important. An effective communication plan outlining what to communicate, what not to communicate, and creating/aligning reactive statements in case something does not happen according to plan is essential to mitigate risks. We recommend that engagement with stakeholders (described in section 5.2.1), international bodies (described in section 5.2.3), and local jurisdictions (described in section 5.2.4) be undertaken. The development of a robust communication plan is highly advised.

Technical reviews are a means to promote quality control, validate the scope, monitor and control project tasks, and identify and manage risks. They promote excellence and proper requirement elicitation and strengthen the project outcomes. To ensure scientific robustness and credibility, an international steering committee should be established to oversee the development of the survey methods, noise modeling approaches, and metrics. This committee would be responsible for ensuring that the methods used are appropriate for deriving a nationally-representative dose-response relationship and that the survey design does not introduce bias. When applicable, the steering committee should also see that these techniques and/or data are harmonized globally, enabling future meta-analyses across different countries.

Finally, it is recommended that the seven data protection principles outlined in sections 5.6.2 to section 5.6.8 are followed to reduce risks, build trust, promote good governance and operational efficiency, and demonstrate international alignment.

8. Milestones and Key Decision Points

This section outlines the major milestones and key decision points (KDPs) across the three-year planning phase of the project. Each milestone or KDP includes a brief description, target timeframe, and exit criteria. This section should be read in combination with the preferred approach detailed in section 7. This project plan should be reviewed in parallel with reviews from the other IRTs to develop the final project plan.

The proposed project timeline is divided into four sequential phases shown in Figure 4: Kick-off, Development, Pilot Test and Methodology Refinement.

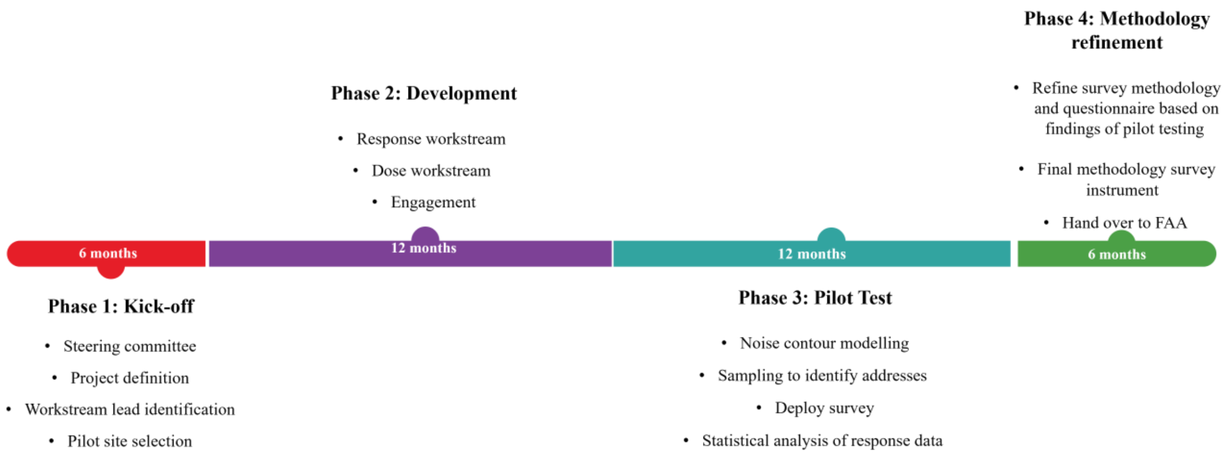

Figure 4 Proposed project timeline

Each of these phases is outlined in the following sections. The name of the activity, its description, start and duration, dependencies, and exit criteria are shown in each table. A Gantt chart is presented at the end of the section.

8.1 Phase 1: Kick-off (Months 0–6)

	Activity	Description	Due Date	Dependencies	Exit Criteria
1.1	KDP: Setup steering committee	Identify and invite key stakeholders to steering committee	Month 1–2		Steering committee established
1.2	Define project monitoring and reporting requirements	Define frequency and structure of progress reports	Month 1		Progress report structure and input of reporting dates in the project plan / Gantt chart
1.3	KDP: Project definition	Define objectives, timeline, deliverables, and communication plan	Month 2		Documented project plan
1.4	KDP: Identify workstream leads	Assign leads and define responsibilities for dose, response, and engagement workstreams	Month 2–3	Depends on 1.1	Responsibility matrix completed
1.5	Stakeholder workshop	Initial engagement with NASA, FAA, and others to elicit project requirements	Month 3	Depends on 1.1	Workshop completed and feedback documented
1.6	Milestone: Definition of project requirements	Project requirements document reflecting outcomes of stakeholder workshop	Month 4	Depends on 1.3 and 1.5	Project requirements agreed
1.7	Workstream kick-off meetings	Launch dose, response, and engagement workstreams	Month 5	Depends on 1.6	Workstreams operational
1.8	KDP: Pilot site selection	Select site(s) for model validation and pilot testing	Month 6	Depends on 1.6	Sites confirmed

8.2 Phase 2: Development (Months 6–18)

	Activity	Description	Due Date	Dependencies	Exit Criteria
		Phase 2.1 Response workstream			
2.1.1	KDP: Survey mode decision	Select mode(s): in-person, postal, telephone, web, or mixed	Month 7–9		Survey mode finalized
2.1.2	Laboratory testing	Conduct lab studies to inform survey design	Month 7–18		Laboratory testing completed and findings incorporated into methodology
2.1.3	Questionnaire design	Develop questions, source definitions, and non-acoustic factors	Month 9–12	Depends on 2.1.1	Draft questionnaire ready for user testing
2.1.4	User testing of UAM definitions	User testing of the main annoyance questions and definitions used in the questionnaire	Month 12–14	Depends 2.1.3	Draft questionnaire ready for peer review
2.1.5	Develop pilot survey methodology	Development of pilot survey methodology, including sampling method and logistics	Months 7 - 15		Draft methodology ready for peer review
	Workshop on response activities				
2.1.6	Peer review of pilot questionnaire and pilot survey methodology	Peer review of questionnaire and survey methodology, allowing for two rounds of review and feedback	Month 15 - 18		Approved methodology peer review board
2.1.7	Milestone: Methodology and questionnaire for pilot testing		Month 18		Peer reviewed survey methodology and questionnaire
		Phase 2.2 Dose workstream			
2.2.1	Develop a model of selected site with appropriate level of complexity			Depends on 1.8	
2.2.2	KDP: Decide on candidate noise modeling approach(es)		Month 7–9	Depends on 2.2.1	
2.2.3	Define input data requirements for selected modeling approach(es)	Specify data needs (e.g. NPD, operations)	Month 12–15	Depends on 2.2.2	Input requirements documented
2.2.4	Sensitivity testing of selected modeling approach(es)	Compare modeling approaches (e.g. AEDT vs. urban propagation models)	Month 10–14	Depends on 2.2.1 and 2.2.3	Preferred modeling approach selected

	Activity	Description	Due Date	Dependencies	Exit Criteria
2.2.5	Milestone: Progress report on selected modeling methodology				
2.2.6	Noise modeling workshop				
2.2.7	Develop noise monitoring plan for model validation	Define monitoring approach and locations	Month 7–9	Depends on 1.8	Monitoring plan completed
2.2.8	Develop ambient characterization methodology	Validate selected ambient model	Month 10–14	Depends on 2.2.7 (noise monitoring)	Ambient modeling tool validated
2.2.9	Initial Modeling Tools	Define methodology and tools	Month 14		Draft tools delivered
2.2.10	Model Validation	Validate selected method and NPD curves	Month 15–18	Depends on 2.2.7 (noise monitoring)	Final methodology validated
Phase 2.3 Engagement workstream					
2.3.1	Data Acquisition	Obtain ADS operation and NPD data	Month 7-9	Depends on 2.2.3	Data received
2.3.2	Legal and Privacy Review	Review state data laws and conduct data impact assessment	Month 9–12		Data impact assessment
2.3.3	Local Engagement	Engage with jurisdictions and develop communication plan	Month 12–18		Engagement plan approved
2.3.4	Overarching workshop (dose and response workstreams)				
2.3.5	Pilot Test Methodology	Documented pilot test design	Month 18		Methodology approved

8.3 Phase 3: Pilot Test (Months 18–30)

	Activity	Description	Due Date	Dependencies	Exit Criteria
3.1	Noise contour modeling	Generate noise contours for site(s)	Month 18–21	Depends on 2.2.10	Contours completed
3.2	Sampling	Identify addresses	Month 21–22	Depends on 3.1	Survey deployed
3.3	Questionnaire deployment	Deploy survey	Month 23 - 26		
3.4	Data Analysis	Analyze response data	Month 26–30	Depends on 3.1 and 3.3	Analysis completed
3.5	Milestone: Report on pilot survey		Month 30		Pilot survey report issued

8.4 Phase 4: Refinement and Handover (Months 30–36)

	Activity	Description	Due Date	Dependencies	Exit Criteria
4.1	Methodology Refinement	Update survey methodology and questionnaire based on pilot findings	Month 30–34		Final methodology approved
4.2	Final Survey Instrument	Final version of questionnaire	Month 34	Depends on 4.1	Instrument finalized
4.3	Handover to FAA	Transfer methodology and tools	Month 36	Depends on 4.1 and 4.2	Handover completed

Ref	Phases/Activities	Dependencies	Year 1				Year 2				Year 3			
			Q1	*Q2*	*Q3*	*Q4*	*Q1*	*Q2*	*Q3*	*Q4*	*Q1*	*Q2*	*Q3*	*Q4*
	Phase 1													
1.1	KDP: Setup steering committee													
1.2	Define project monitoring and reporting requirements													
1.3	KDP: Project definition													
1.4	Identify workstream leads	1.1												
1.5	Stakeholder workshop	1.1												
1.6	Milestone: Definition of project requirements	1.3 and 1.5												
1.7	Workstream kick-off meetings	1.6												
1.8	KDP: Pilot site selection	1.6												
	Phase 2.1: Response related													
2.1.1	KDP: Survey mode decision													
2.1.2	Laboratory testing													
2.1.3	Questionnaire design	2.1.1												
2.1.4	User testing of UAM definitions	2.1.3												
2.1.5	Develop pilot survey methodology													
	Workshop on response activities													
2.1.6	Peer review of pilot questionnaire and pilot survey methodology													
2.1.7	Milestone: Methodology and questionnaire for pilot testing													
	Phase 2.2: Dose related													
2.2.1	Develop a model of selected site with appropriate level of complexity	1.8												
2.2.2	KDP: Decide on candidate noise modelling approach(es)	2.2.1												
2.2.3	Define input data requirements for selected modelling approach(es)	2.2.2												
2.2.4	Sensitivity testing of selected modelling approach(es)	2.2.1 and 2.2.3												
2.2.5	Milestone: Progress report on selected modelling methodology													
2.2.6	Noise modelling workshop													
2.2.7	Develop noise monitoring plan for model validation	1.8												
2.2.8	Develop ambient characterization methodology	2.2.7												
2.2.9	Initial Modelling Tools													
2.2.10	Model Validation	2.2.7												
	Phase 2.3: Engagement													
2.3.1	Data Acquisition	2.2.3												
2.3.2	Legal and Privacy Review													
2.3.3	Local Engagement													
2.3.4	Overarching workshop (dose and response workstreams)													
2.3.5	Pilot Test Methodology													
	Phase 3: Pilot Test													
3.1	Noise contour modelling	2.2.10												
3.2	Sampling	3.1												
3.3	Questionnaire deployment													
3.4	Data Analysis	3.1 and 3.3												
3.5	Milestone: Report on pilot survey													
	Phase 4: Refinement and handover													
4.1	Methodology Refinement													
4.2	Final Survey Instrument	4.1												
4.3	Handover to FAA	4.1 and 4.2												

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10. List of Acronyms

AAM	Advanced Acoustic Model
AEDT	Aviation Environmental Design Tool
AIR	Aerospace Information Report
AMBIENT	Ambient noise model by BRRC
ANCM	Aircraft Noise Contour Model (Spain)
ANCON	Aircraft Noise Contour Model (UK CAA)
ANOPP	Aircraft Noise Prediction Program
ANOMS	Airport Noise and Operations Monitoring System
ANP	Aircraft Noise and Performance
ANSI	American National Standards Institute
ARP	Aerospace Recommended Practice
BADA	Base of Aircraft Data
BRRC	Blue Ridge Research and Consulting
BSI	British Standards Institution
BTS	Bureau of Transportation Statistics
CAMRAD	Comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics
COTS	Commercial Off-The-Shelf
DEM	Digital Elevation Model
DENL	Day-Evening-Night Level
DLR	The German Aerospace Centre
DNL	Day-Night Level
DoT	Department of Transportation
DSM	Digital Surface Model
DTM	Digital Terrain Model
ECAC	European Civil Aviation Conference
eVTOL	Electric Verical Take off and Landing
FAA	Federal Aviation Administration
FANOMOS	Flight Track and Aircraft Noise Monitoring System (Netherlands)
FICAN	Federal Interagency Committee on Aviation Noise
GDPR	General Data Protection Regulation
ICBEN	International Commission on the Biological Effects of Noise
ICAO	International Civil Aviation Organization
IEC	International Electrotechnical Commission
IMPACT	Integrated aircraft noise and emissions modeling platform
IPR	Intellectual Property Rights
IRT	Independent Review Team
ISO	International Organization for Standardization
KDP	Key Decision Points
L_{Aeq}	A-weighted Equivalent Continuous Sound Level
L_{Amax}	Maximum Sound Level
MDS	Multidimensional Scaling
MEMS	microelectromechanical systems
NASA	National Aeronautics and Space Administration
NEF	Noise Exposure Forecast
NES	Neighborhood Environmental Survey
NOICE	Noise Impact Calculation for the Environment (Italy)
NORAH	Noise of Rotorcraft Assessed by Hemisphere

NPD	Noise-Power-Distance
N_x	Number-above (event count metric)
N_{xDNL}	Number-above Day-Night Level
OIRA	Office of Information and Regulatory Affairs
OEM	Original Equipment Manufacturer
OMB	Office of Management and Budget
PANAM	Prediction of Aircraft Noise And emissions Model
PIANO	Propeller noise prediction tool
PML	Perfectly Matched Layer
PRA	Paperwork Reduction Act
RANE	Rapid Aviation Noise Evaluator
SAE	Society of Automotive Engineers
SonAIR	Swiss aircraft noise prediction tool
SONYC	Sounds of New York City
STAPES	SysTem for AirPort noise Exposure Studies
sUAS	Small Unmanned Aerial Systems
TAU	Tool for Aircraft noise prediction at component level
UAM	Urban Air Mobility
UNWG	UAM Noise Working Group
VTOL	Verical Take off and Landing
WECPNL	Weighted Equivalent Continuous Perceived Noise Level
WHO	World Health Organization

Appendix A

A.1 Summary of Aviation Noise & Emission Models

The following table summarizes the capabilities of the aviation software outlined in section 3.2.1.

	AEDT	ANCON	IMPACT	STAPES	NORAH2	RANE	AAM	ANOPP2	PANAM	SonAIR
Developer	Federal Aviation Authority (USA)	Civil Aviation Authority (UK)	EUROCONTROL (FR)	EUROCONTROL (FR)	European Union Aviation Safety Agency (EU)	ISVR, University of Southampton (UK)	NASA (US)	NASA (US)	DLR (DE)	EMPA (CH)
Released	2015	1992	2008 / 2009	2009	2021	2017	2020	2016	2000	2018
Primary Use	Regulatory assessments, unified (noise, carbon, emissions) assessments	Regulatory contours for UK airports	Detailed assessment, procedure design (fuel burn / emissions vs noise)	Regulatory assessments, population exposure	Rotorcraft within regulatory assessments (eg END)	Quick assessment of airport noise emission	UAM, drone, future vehicles	Unconventional aircraft assessments	Quick assessment of aircraft noise	High resolution aircraft & airport noise prediction
Model Type	Empirical (NPD)	Empirical (NPD)	Hybrid (NPD)	Empirical (predominantly)	Empirical	Empirical (NPD)	Hybrid	Theoretical (physics-based)	Hybrid	Hybrid
Integrations	Already combines legacy software into one: INM, EDMS & NIRS	Part of the CAA aviation software managed by ERCD	Part of the EUROCONTROL environmental suite	Integrates with IMPACT	Standalone	Standalone	Integrates with other NASA tools	Integrates with other NASA tools	Other DLR tools (PrADO, SHADOW, etc)	GIS Platforms
Validation	FFA	Against measurements at LHR, GAT & STN	ICAO CAEP/10	Through IMPACT	Against measurements	ISVR	Measurement & simulation	Measurement & simulation	Measurement	Measurement
Noise Sources	Airframe & engines, rotorcraft	Airframe & engine	Airframe & engine	Airframe & engine	Rotorcraft	Airframe & engines	Airframe, engine, rotorcraft, installation & interaction effects	Airframe, engine, rotorcraft, installation & interaction effects	Airframe, engine (& installation effects with SHADOW)	Airframe, engine, rotorcraft
Regulatory Status	Required in US by NEPA	Required in UK for airport contours	Recommended under SESAR (Single European Sky ATM Research) program	Recommended under SESAR (Single European Sky ATM Research) program	Recommended for END assessment	None	None	None	None	Swiss National Model (from 2026)
Output	One third octave & broadband	Broadband only	Likely broadband only	Likely broadband only	One third octave & broadband	Broadband only	One third octave & broadband	One third octave & broadband	Broadband (primarily)	One-third octave, broadband
Source Directionality	Simple azimuth	Doc29 method	Doc29 method	Doc29 method	Hemispherical, from measurements	None	Three-dimensional, spectral spherical directionality	Three-dimensional, spectral spherical directionality	Component-based, empirical	Three-dimensional, spectral spherical directionality
Flight Path Detail	Procedural, mean + dispersion & real-world	Mean tracks + dispersion from real-world tracks	Procedural, mean + dispersion & real-world	Procedural, mean + dispersion & real-world	Four-dimensional tracks (incl. time) & custom rotorcraft procedures	Simplified	Real-world tracks & custom UAM procedures	Multi-dimensional tracks (incl. time, configuration, state)	Multi-dimensional tracks (incl. time, configuration, state)	Detailed, real-world, four-dimensional tracks, procedural

Table 3 Summary of existing aviation noise and emissions models.

Appendix D BRRC Final Report

Blue Ridge Research and Consulting, LLC

Technical Report 25-09 (Final)

NASA UAM Community Response Test Preparation: An Independent Technical Review

27 July 2025

Prepared for:
Stephen Rizzi, NASA Langley
under Analytical Mechanical Associates Contract
SOW # RSES.C2.02.00675
(757) 864-3599
s.a.rizzi@nasa.gov

Blue Ridge Research and Consulting, LLC
29 N Market St, Suite 700
Asheville, NC 28801
828.252.2209
BlueRidgeResearch.com

Prepared by:
Juliet Page
Shane Lympany
Blaine Harker
Micah Downing

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1 INTRODUCTION

Blue Ridge Research and Consulting, LLC (BRRC) appreciates the opportunity to provide feedback on National Aeronautics and Space Administration (NASA) considerations for a possible future technical challenge. BRRC encourages the release of the white paper publicly and to proactively gather feedback. We have drawn from related aviation-adjacent research and our team's collective experiences to provide a critique of the NASA scoping document. We also provide a high-level discussion of relevant references.

BRRC recommends that NASA utilize a multidisciplinary and multistakeholder process to develop a list of research questions that will inform both the Federal Aviation Administration (FAA) and the Urban Air Mobility (UAM) industry. BRRC suggests that the NASA team develop a *preliminary* test protocol with *sufficient detail* to inform the test design process and elucidate a Revolutionary Vertical Lift Technology (RVLT) technical challenge.

BRRC thinks that the technical challenges should reach beyond the Government Furnished Information (GFI) indicated justification (which is gathering credible scientific information to inform the FAA via a long-term dose-response relationship for UAM) and should also serve the UAM industry's needs. BRRC questions the justification of *only* using the need to provide technical guidance to the FAA regarding a future dose-response test as the rationale for an RVLT challenge and encourages NASA to engage directly with UAM industry members.

The parallels to the successful Quesst Mission budget justifications, namely the need to provide technical support to the FAA, are obvious. However, in the supersonics arena, the FAA technical justification encompasses both the need for new supersonic regulations (noise certification both enroute and in the terminal area) and the need for credible scientific data to overturn the existing "no civil supersonic flight" law (14 CFR 91.817). For supersonics, evaluation of the dose-response requires a purpose built low-boom flight vehicle, which necessitates a substantial investment beyond the scope of a single Original Equipment Manufacturer (OEM). The FAA has already demonstrated progress toward advancing UAM certification in coordination with industry; and in the case of UAM, existing laws do not need to be overturned prior to UAM operations in the national airspace.

BRRC suggests that the intended NASA white paper publication in Fall 2025 be made in conjunction with online webinars and suitable mechanisms for engaging a range of stakeholders, including OEMs.

1.1 NASA Scoping Document Considerations

The NASA "Scoping Document for Urban Air Mobility Community Response Test Preparation" (NASA, 2025) contains a wealth of open topics related to future dose-response testing, organized into three functional yet highly interrelated arenas: dose-related, response-related, and other. The nationally representative long-term dose-response test design is noted in the Objectives section as a "NES-like study", where NES means Neighborhood Environmental Survey, which to us implies:

- Home address recruitment,
- One-time survey over the 'last year while at home' compatible with historical surveys,

- Relevant noise source annoyance question buried amongst other community questions,
- Day-Night Average Sound Level (DNL) vs. Percent Highly Annoyed (%HA),
- Dose is determined by modeling,
- No acoustic monitoring is conducted,
- Non-Emerging Technology Aircraft (ETA) noise is not a consideration.

A NASA secondary objective, to investigate the relative contribution of small Unmanned Aircraft Systems (sUAS) relevant to ETA vehicle is noted, but principally due to similar operating environments and the potential for the public to convolve their perceptions of sUAS and UAM.

The FAA has noted[*] that the NES dose-response data indicates that "there has been a substantial change in the public perception of aviation noise relative to the Schultz curve." FAA also notes that "potential factors for these differences still need to be explored" and suggest that these results "will ultimately inform future FAA noise initiatives." These unexpected results led to the FAA initiating a noise policy review (NPR). In 2024, the Congressional reauthorization[†] directed the FAA to establish the Aircraft Noise Advisory Committee[‡] (ANAC) comprised of stakeholders across the aviation industry, institutions of higher education and community representatives. The FAA has not described how the dose-response curves will be used in policy development for aviation noise and NASA has not articulated *how* they plan to use NES science to help guide the FAA. Instead, we are left questioning the questions. Why the Schultz curve? Why DNL? Why is 65 dB the threshold for land use compatibility? Why repeat a NES-like study? Do we want a repeat of largely unexplainable results?

We recommend that NASA broaden the Objectives section of the scoping document before public release. We found that the GFI test details were insufficient to do anything other than repeat NES for UAM. As part of the preferred approach, we developed a test skeleton as a helpful, self-organizing screening method to assess and prioritize test elements and test design decisions, to identify the technical gaps and articulate the associated rationale.

1.2 Task Introduction

The statement of work indicates that BRRC is to provide a comprehensive, independent technical review of the NASA Scoping Document (GFI item 9.1). The specific elements of the scope include:

- 2.2.1. Identify activities that are either *missing* (not represented in the Scoping Document) or that are unnecessary and provide the associated rationale.
- 2.2.2. Identify *alternative* approaches and/or activities to accomplish the same objectives identified in Section 2 of the Scoping Document and provide the associated rationale.
- 2.2.3. Identify a *preferred* approach from the intersection of activities associated with 2.2.1 and 2.2.2 and provide the associated rationale.
- 2.2.4. For the preferred approach in 2.2.3, provide *detailed descriptions of activities* down to the lowest level practical including an assessment of the level of maturity and identification of technical risks for each.

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[*] https://www.faa.gov/regulations_policies/policy_guidance/noise/survey. Accessed 23 June 2025

[†] FAA Reauthorization Act of 2024, Section 792

[‡] https://www.faa.gov/noisepolicyreview. Accessed 23 June 2025

- 2.2.5. Identify significant *milestones* and any key decision points (KDPs), each with a brief description, due date, and exit criteria, assuming a 3-year total duration from start to finish. This timeframe would allow the test preparation work to be completed prior to the test(s) being executed.
- 2.2.6. Provide a notional *Gannt* chart showing key milestones and KDPs, tasks, start and end dates, and dependencies.

To this end, Section 2 discusses the NASA GFI Scoping document and identifies activities that are either *missing* or unnecessary and provides technical background, discussion, and rationale (2.2.1). Section 3 discusses alternative approaches and activities that meet the same objectives (2.2.2). Throughout Sections 2 and 3, where appropriate, suggestions to NASA for Scoping document revisions are provided in ***italics*** while open technical questions are ***emphasized***. Alternative Approaches and considerations are documented in Section 3.

Section 4 outlines BRRC's preferred dose-response test approach in the form of a skeleton test. We found that a working dose-response test design helped to identify, prioritize, and develop the research activities. Section 4 also discusses the technical questions that came to light during the skeleton test development and highlights unsettled research gaps that emerged as part of identifying and explaining our preferred approach rationale. To the extent possible, we detailed our preferred dose-response test approach and rationale in Section 4.

Section 4.8 describes our recommendations for various research activities needed to prepare for the execution of the preferred testing approach, and the open scientific questions the activities need to answer. Section 4.8 also describes an assessment of the level of maturity and identification of risks for the activities.

A graphical format of a notional research roadmap in timeline format, including significant milestones and key decision points, is provided in Section 6. The sequence of discussion in Sections 2 to 4.8 is organized to reflect the statement of work with subcategories organized like the GFI: Dose-Related, Response-Related, and Other Activities.

2 SCOPING DOCUMENT DISCUSSION AND IDENTIFICATION OF MISSING AND UNNECESSARY ACTIVITIES

NASA has provided as Government Furnished Information (GFI) a scoping document entitled "Urban Air Mobility Community Response Test Preparation" (NASA, 2025), which notes the objectives, framework, and ground rules for future subjective testing to be conducted by the FAA Office of Environment and Energy (AEE-100).

The NASA-stated FAA goal is to develop a nationally representative long-term dose-response relationship for larger Emerging Technology Aircraft (ETA). The GFI also outlines possible future NASA activities that form the basis of a technical challenge for the NASA Aeronautics Research Mission Directorate (ARMD) Advanced Air Vehicle Program (AAVP) Revolutionary Vertical Lift Technology (RVLT) Project.

This section mirrors the NASA scoping document. Here are our high-level observations:

- Describing how the FAA will use the dose-response relationship will help test planning.
- Important distinctions and questions that arise between Schultz, FICON, and NES curves open the door to suitable NASA-led research.
- If NASA is indeed supporting (actively or passively) the FAA NPR process, this should be noted as it provides a wealth of justification for NASA-led UAM research.
- The possibility of hybrid dose evaluation procedures should be considered and noted.
- Differentiation between three modeling elements (propagation, source, and operational modeling strategy) would be useful for validation activities.
- Deriving and transforming limited measurement data with application of modeling results, approximations, and surrogate data should be explored.
- Appropriate measures for quantifying the statistical structure of the ambient environment where people reside for use in perception evaluation should be explored.
- Development of a noise monitoring strategy for the FAA dose-response test should be prioritized facilitating identification of opportunities for combined in situ acoustic tests.
- In the context of a non-steady UAM operational tempo, the appropriate time scale needs to be determined to capture the noise exposure to a study participant.
- NASA should prioritize an operational scenario analysis to quantify the future operations with sufficient granularity to inform subsequent FAA efforts to develop a nationally representative long-term dose-response relationship.
- Development of local geographically individualized dose-response relationships and separation of dose-responses by UAM aircraft category are not consistent with the objective of developing a nationally representative UAM dose-response relationship.
- Methods are needed to relate both noise and number of events annoyance gathered in a laboratory setting to long-term annoyance.

The NASA scoping document and tasks require a detailed assessment of necessary technologies to create an updated NES-like dose-response relationship for larger ETA. Even though NASA is not going to develop regulation, the potential uses of the dose-response relationship should be defined so an informed research plan can be developed. One clue about how FAA might apply this new relationship may be found on the FAA website,* indicating that the "Survey results show that there has been a substantial change in the public perception of aviation noise, relative to the Schultz Curve, and will ultimately inform future FAA noise initiatives." As such, many of the comments here regarding test preparation are based on presumptions of how the FAA might eventually apply such scientific knowledge, and hence what details are likely to be needed. Ultimately, NASA research decisions and funding should be prioritized based on potential FAA actions if NASA's stated primary and secondary FAA support goals remain as is.

In this section, BRRC offers suggestions for potential updates and other technical considerations for the dose response testing. These updates and considerations are supported by background material, discussions, and rationale that are provided in the following sections of the report. A narrative discussion, including suggested edits and clarifications† to the elements contained in the NASA GFI, may be found in the following sections.

- "Background" Section 2.1
- "Objectives" Section 2.2
- "Scope" Section 2.3
- "Dose-Related" Section 2.4
- "Response-Related" Section 2.5
- "Other Activities" Section 2.6

2.1 Background

The background section of the scoping document provides a good summary of past work in aviation noise dose-response testing, and notes the need for understanding community response specific to UAM noise. Parallels to the NASA Quesst mission are drawn, and differences are highlighted. Specific suggested scoping document revisions are noted below.

2.1.1 Revise NASA Goal and Correct Stated FAA NES Goal

Within the scoping document NASA should revise the sentence describing the FAA NES goals indicating 'aircraft produced noise exposure.'

The NASA scoping document notes that "Recently, the Neighborhood Environmental Survey (NES) study sought to update the Schultz curve and focused on fixed-wing aircraft noise." However, the NES final report notes that "The overall goal of this research effort was to produce an updated and nationally representative dose-response curve that quantifies the relationship of peoples' surveyed annoyance response to aircraft produced noise exposure in the US." FAA recognizes the original Schultz curve (Schultz, 1978) and updated Federal Interagency Committee on Noise (FICON) curves (FICON, 1992) both include multi-modal transportation (see Figure 1). The FAA NES dose-response study target is "aircraft produced noise exposure," which also includes civil and military fixed wing and rotorcraft operations.

* https://www.faa.gov/regulations_policies/policy_guidance/noise/survey "Schultz Curve" Section. Accessed 23 June 2025.

† Suggested edits to the document may be found in *italics*, and questions that BRRC recommends incorporating into NASA's technical research plans are ***emphasized***.

2.1.2 Note the FICON DNL Metric Reaffirmation

Within the scoping document NASA should clarify that the DNL metric use was affirmed by FICON in 1992 and accepted by the FAA.

In 1979, the Aviation Safety and Noise Abatement Act (ASNA) was established. In 1981, this act was implemented by the FAA in 14 CFR Part 150*. In 1992, FICON revisited the Schultz data and recommended the continued use of the DNL metric as the primary descriptor for determining acceptable long-term noise exposure of civil and military aircraft operations.

2.1.3 Distinguish Between Legacy Schultz and Updated FICON Curves

Somewhere within the scoping document, NASA should point out important distinctions and questions that arise between Schultz, FICON, and NES curves that open the door to suitable NASA-led research.

FAA makes a distinction between the original Schultz and the updated FICON curve fits and specifically refer to it on the FAA website under the rationale section:† "The last in-depth review and revalidation of the Schultz Curve was conducted in 1992." The 1992 reference is also noted in the FAA NES report (Miller et al, 2021, Executive Summary and Section 1, p.1). Differences between the original Schultz and later FICON curve fit occur between 55 to 75 dB DNL and above 85 dB DNL. The difference in the curves near 65 dB DNL could be important for UAM noise and the locations where dose-response testing happens (especially if surveying happens near vertiports and airports).

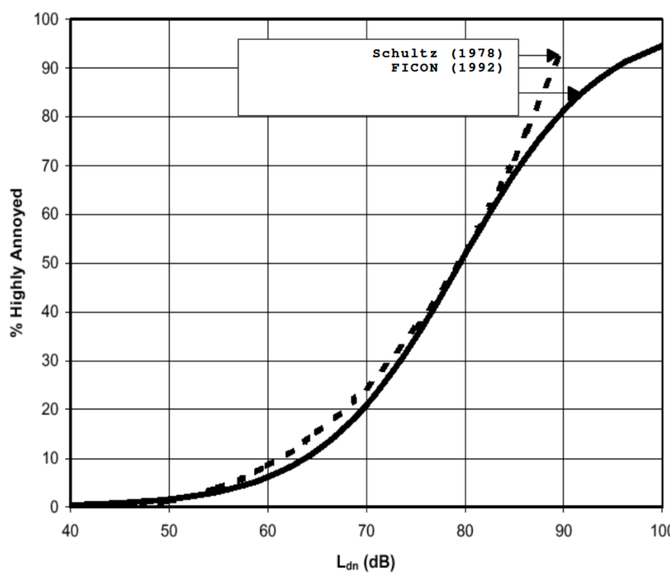

Figure 1. Schultz (1978) and FICON (1992) community response curves in dashed and bold lines, respectively. *(Source: DNWG, 2009)*

The DNL 65 dB level was reaffirmed by FICON for determining acceptable noise exposure in residential areas for the purpose outlined in ASNA. Beyond civil aviation concerns, the US

* The FAA periodically updates 14 CFR Part 150

† https://www.faa.gov/regulations_policies/policy_guidance/noise/survey

Department of Defense (DoD) also bases their land use policy for airfields on FICON, 1992 and employs the DNL metric (DNWG, 2009). The FICON curve suggests that 12.3 percent of people are highly annoyed by a DNL of 65 dB. The NES national dose-response curve shows that nearly two-thirds of people are highly annoyed at DNL 65 dB. The FAA notes this considerable difference between FICON and NES results. This could impact both the FAA and DoD policy development related to acceptable noise exposure for residential areas. The 65 dB DNL level is in essence a threshold for compatibility.

The quiet nature of UAM vehicles compared to other aviation noise sources, implies that the test design should be carefully constructed to obtain sufficient data at the lower DNL levels to evaluate the effect of DNL increase on response in the lower DNL range.* The FICON report (1992) also discusses changes to existing noise levels and recommends that, "If screening analysis shows that noise-sensitive areas will be at or above DNL 65 dB and will have an increase of DNL 1.5 dB or more, further analysis should be conducted of noise-sensitive areas between DNL 60-65 dB having an increase of DNL 3 dB or more due to the proposed airport noise exposure." FICON has opened the door for analysis of exposure (and exposure changes) at lower DNL levels.

2.1.4 Parallels to the NASA Quesst X-59 Mission

NASA should note the short-term vs. long-term cumulative survey difference between Quesst and the intended UAM research (and NES). BRRC suggests assessing these differences with a longitudinal survey to evaluate trends in each community's annoyance relationship to changes in UAM operational tempo.

The Quesst program is tasked with gathering dose-response data using the purpose-built X-59 low boom flight demonstrator. The project is gathering both single-event and short-term cumulative annoyance, as evidenced by including daily summary response survey questions. Short-term (daily) cumulative annoyance – as has also been gathered for previous sonic boom community tests Waveforms and Sonic Boom Perception and Response (WSPR2011) (Page et al., 2014) and Quiet Supersonic Flights (QSF18) (Page et al., 2020) – is not necessarily the same thing as long-term (annual) cumulative annoyance. The communities participating in the dedicated sonic boom tests have only experienced operational flight test durations of about one month. The acclimation period for low booms and for UAM noise exposure is presently unknown. Daily survey results will allow for the evaluation of annoyance with integrated energy cumulative metrics. With the possibility for increasing UAM flight operational tempo over the course of a full year (as is the standard for assessing long-term annoyance), the possibility of repeated short-term cumulative annoyance measurements could provide valuable insights for interpretation of a long-term cumulative dose response relationship.

* The Federal Transit Administration noise impact criteria (FTA, 2018) is described relative to existing (ambient) noise, furthering the need to consider lower levels of UAM noise exposure in the test design.

2.2 Objectives

2.2.1 Overview

Although the objective is to follow a NES-like study, BRRC recommends adding additional elements to enhance application of the results - learning from and improving upon the NES study.

NASA's white paper will help focus the research efforts of the broader acoustics community on technologies required for the FAA to develop a nationally representative long-term dose-response relationship for emerging technology aircraft (ETA). NASA notes that such dose-response relationships are necessary to inform policy (e.g., land use and environmental) at the federal, state, and local levels. NASA's secondary objective is to investigate the relative contribution of small UAS (sUAS)[*] as they relate to the ETA or UAM[†] community noise environment. The scoping document states that a "NES-like study is envisioned." BRRC interprets a "NES-like study" to mean:

- Participants are recruited and surveyed based on their home address
- A one-time survey that asks about annoyance from UAM vehicles over a long duration (e.g., "over the last year")
- Noise dose is calculated based on (validated) modeling results in the absence of any direct measurements in the survey areas during the duration called out in the survey
- The dose-response relationship is computed using DNL (dBA) cumulative metric vs. percent highly annoyed based on established guidelines (FICON, 1992; ISO 2020)
- The survey responses and dose are obtained from multiple geographic locations and combined to obtain a nationally representative sample
- 'Nationally representative' implies balanced sampling across demographics, transportation noise sources (ETA configurations / operational modes, commercial / military aircraft, road and rail noise) and meteorological / environmental conditions and population density
- Non-ETA noise (including ambient noise) is not a consideration

This interpretation means that the preparatory research NASA needs to conduct is related to validating the model that computes DNL and quantifying the dose uncertainty at the participants' home addresses. Model validation includes the source acoustic emission, the propagation to the receiver, confirming the flight paths and operational tempo and confirming cumulative metrics calculations at points of interest. As part of the validation, the process for obtaining input data for the DNL model and the uncertainties it introduces must be examined. Based on modeling, monitoring, and surveys, a NES-like DNL dose-response curve can be obtained for UAM.

[*] The authors interpret the sUAS term to include all unmanned flight vehicles smaller than the air taxi sized passenger carrying UAM vehicles. This includes package delivery vehicles and smaller hobbyist drones.

[†] FAA uses the term Emerging Technology Aircraft (ETA) to include Unmanned Aircraft Systems (UAS), Advanced Air Mobility (AAM) vehicles like air taxis, commercial space vehicles, and supersonic aircraft. NASA and this report use the term Urban Air Mobility (UAM) to refer to the larger manned air taxi vehicles.

2.2.2 Recommended Additional Questions

While NASA notes that 'other measures of dose and response *may* be investigated', the emphasis of the objectives section is an NES-like study and NASA's interest in these other measures needs to be emphasized. BRRC thinks that following an NES-like study is too simplistic and restrictive for a NASA technical challenge, and the result will likely leave open many unanswered scientific questions. BRRC has interpreted the GFI that an identical NES-like study is not the sole intent of NASA's explorations[*]. BRRC suggests the following questions *in blue* be considered for inclusion in the scoping document.

1. ***What is the expected operational tempo of UAM operations in communities?***

   New UAM operations will be introduced gradually, then ramped up as manufacturers build and deliver the vehicles and industry incorporates them into daily operations. For the purposes of dose-response test planning, insights are needed on the speed of introduction of UAMs into the airspace and realistic operational tempos that are expected during the stated dose-response test time period (~2030).

2. ***Are there particular elements of UAM sounds that affect dose-response differently in these operational zones and are metrics able to capture these?***

   It is expected that the sound quality and tonal versus broadband content of UAM noise will be different near the vertiport (potentially with dynamically changing hover and transition modes with more tones) versus enroute zones with a more uniform and steady flight segment dominated by broadband sounds.

3. ***What is the best way to quantify the dose and its uncertainty?***

   When considering "other measures of dose and response" as noted in the GFI objectives section, alternate dose evaluation techniques have been considered and are utilized by others. Typically, a model is used to evaluate the long-term dose considering annual operations (e.g. Miller, 2021), but alternate annual modeling techniques have been explored. For example, the 95th percentile day, the busiest traffic day, methods based on runway usage (Jovanovic, 2023), the US Air Force Average Busy Day,[†] or the more recently utilized US Navy Average Busy Day[‡] are all accepted dose evaluation techniques.

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[*] Budget and labor considerations might necessitate additional adjustments to the research activity prioritization and scope.

[†] Noise from the average busy day is based on operational modeling obtained by computing the workday average for each month, then averaging the twelve values. USAF notes that other than average busy day operational levels may be appropriate where analysis indicates that peak or seasonal averages would not properly reflect the noise environment (DoD, 1978).

[‡] In US Navy Air Installations Compatible Use Zone (AICUZ) studies, average busy day is defined as a typical day when the airfield is in full operation. A day is considered busy when its total operations are at least 50% of the average annual daily operations. One AICUZ study (NAVFAC, 2002) notes that using the average busy day operations in the noise modeling is a better indicator of probable community response to long-term aircraft noise exposure.

4. ***Can US DOT policies and procedures for other transportation noise sources provide insight for understanding UAM community response?***

Other administrations within the Department of Transportation (DOT) have developed extensive requirements for noise modeling, analysis methods, and source measurements based on dose-response research for differing modes of transportation (Rylander, 1986; Miedema, 1999). For instance, highway noise is regulated through a series of federal and state regulations (23 CFR Part 722) which dictate approved models and modeling methodologies, detail key noise metrics associated with dose-response, and specify thresholds for impacts to communities.

5. ***What is the influence of the residential in-situ ambient noise on human response and how do you effectively address it in test design?***

The anticipated magnitude of UAM operations have led to vehicles with acoustic signatures and operational designs intended to blend into the ambient soundscape when enroute and outside of the vertiport area.

6. ***What is an appropriate survey method for addressing potentially inaudible sounds?***

A concern for the X-59 community response testing is the possibility that the low-boom vehicle might not be heard amongst a normal background environment and might not trigger highly annoyed responses. Inaudible UAM signals can affect the nature and uncertainty of the dose-response relationship especially for the lowest dose values*. Proactive features† are incorporated into the X-59 single event test design to help obtain direct (unbiased) annoyance response data even in the absence of audible sounds from the X-59. If the UAM acoustic designers are successful with their quiet enroute designs, the validity of an NES-like DNL dose-response curve might result in a low number of percent highly annoyed data points.

7. ***What is the relationship between indoor and outdoor response and vehicle audibility?***

Testing the subjective response difference between indoor and outdoor listening could lead to some interesting insights, especially for enroute regions where UAM vehicles are targeting inaudibility, elevating concerns over non-response. Schultz (1978) notes that correlation between annoyance and noise measurements are "dramatically increased" with the windows open because the "official survey mic and noise to which the subjects are exposed is the same

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* X-59 dose-response modeling is employing a multilevel logistic regression. The issue with very few highly annoyed responses is that you cannot fit the logistic curve, since nearly every response is zero. The result could be: "people are not annoyed below the highest measured dB," although you do not know if people start becoming annoyed at 1 dB, 10 dB, or 30 dB higher than what you measured.

† X-59 will be sending deliberate survey prompts to participants after each X-59 sonic boom event occurs. The survey will ask for an annoyance response before it asks if the boom was heard, thereby limiting bias in the annoyance response. Sonic booms can be perceived and cause annoyance, even if they are inaudible (feeling vibration, low frequency induced rattling, pet reactions, etc.).

noise." BRRC agrees that outdoor to indoor sound transmission is an intractable problem from the perspective of developing a national representative dose-response relationship*.

8. ***What are the non-acoustic factors† that strongly affect community response to UAM noise?***

The GFI objectives section notes that "other measures of dose and response may also be investigated." BRRC recommends that a better understanding of the relationship between non-acoustic variables and annoyance be developed. This omission is a missing element from the scoping document. The Defense Noise Working Group (DNWG, 2009) notes that noise exposure explains 'only about half' of the observed variance in annoyance. In the State of the Science document by the International Civil Aviation Organization (ICAO, 2019), it is noted that 'about one-third of the variance' in annoyance is explained by average L_{dn} noise levels and that non-acoustic factors are in play. The original Schultz document (1978) discusses non-acoustic factors in relation to "sub-neighborhoods where the noise exposure is extreme" and suggests that when people are highly annoyed the effects of non-acoustical variables are reduced. The inverse of this is that non-acoustic factors are more important in sub-neighborhoods where noise exposure is minimal – as could be the case for UAM enroute noise. Fields and Powell (1984) showed for their helicopter dose-response test that the short-term annoyance effect due to non-acoustic factors was similar to the long-term annoyance effect. If this holds true for UAM vehicles, it suggests viable non-acoustic factor research could employ short-term testing.

9. ***What is the human response relationship between acceptable and annoying and how is it influenced by ambient noise levels?***

As originally suggested in the Uber Elevate white paper (2016), UAM manufacturers like Archer and Joby are designing their acoustic signature to blend into the background and are counting on high levels of vehicle production and operations (Archer, 2024; eVTOL News, 2023) and widespread community acceptance to make their business case.

2.3 Scope

If NASA is supporting (actively or passively) the FAA NPR process, this support should be noted in the scoping documents as it provides a wealth of justification for NASA-led UAM research.

BRRC understands the stated limitations that NASA will not develop regulation or policy but would like to understand how NASA perceives engaging with FAA to understand the FAA scientific research needs. A replication of an exact NES-like study for UAM might not be sufficient for extending or reaffirming existing regulation and policy. One must consider that the NES outcomes resulted in the initiation of a FAA noise policy review (NPR) and subsequent FAA

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* This issue was explored during the WSPR project, where some residences were instrumented, principally to gather data that could be utilized to assess the impact of rattle on subjective response. But for QSF18 and X-59 dose response testing, the topic of outdoor to indoor transmission is not being directly explored, rather the climate zones and associated climate zone building construction types (Baechler et al., 2013) are considered in the test site selection process.

† Additional discussion about non-acoustic factor effects on annoyance may be found in Section 3.4.

establishment of the Aircraft Noise Advisory Committee (ANAC) (pursuant to the FAA Reauthorization Act of 2024, Section 792).

As part of the NPR the FAA is*:

- Examining the current use of Day-Night Average Sound Level (DNL) as the primary noise metric for assessing cumulative aircraft noise exposure.
- Reviewing whether to continue to use DNL 65 decibel (dB) with a 1.5 dB change as the metric and threshold for determining significant noise effects in environmental reviews under the National Environmental Policy Act (NEPA) and the limit of residential land use compatibility as detailed in Title 14 Code of Federal Regulations (CFR) Part 150.
- Considering if and how alternative noise metrics may be used in lieu of, as a supplement to, or as a companion to DNL to better inform agency decisions and improve the FAA's disclosure of noise effects.
- Considering additional factors such as the need for additional research.

A dose-response test developed for research purposes versus one developed purely for regulatory and policy needs could entail very different elements and scope. BRRC encourages NASA to better delineate the intent of policy vs. research needs as they relate to future UAM research and dose-response testing and specifically note if the intent is to provide supplementary data and information to the ANAC in support of the FAA NPR.

2.4 Dose-Related

2.4.1 Assumptions:

BRRC agrees that dose evaluation should be based on outdoor sound levels and encourages inclusion of a window open/closed question for single events based on recommendations from Schultz†.

NASA states that "dose evaluation calculations will be based on received outdoor sound levels and will not take into account outdoor to indoor building transmission."

2.4.2 Analyses

The scoping document should identify hybrid measurement – modeling dose evaluation methods as a potential testing approach.

NASA specifies that focus will be on predictive analyses to estimate the noise dose. UAM noise modeling has two important developmental stages to fulfill varying analysis needs: Test Design and Dose Evaluation. These two stages have different validation requirements.

- Test Design - apply 'best available' tools for:
    - Evaluation of single event noise levels

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* FAA noise policy review website: https://www.faa.gov/noisepolicyreview/summary-of-comments

† Schultz (1978) notes the criticality of assessing the outdoor vs. indoor noise stimulus. Regarding Belgian data and the significantly higher correlation with windows open, Schultz writes "if one wishes to increase dramatically the correlation… one should open the windows so that the official survey microphone and noise to which the subjects are actually exposed [is] the same noise."

- Evaluation of multiple event noise contours around vertiports and under enroute flight paths for UAM vehicles
- Assessment of the importance of UAM fleet mix on community exposure metrics
- Evaluation of meteorological, seasonal and geographic variability for potential UAM dose-response test sites
- Test planning for limited duration noise measurements
- Creation or adaptation of a range of UAM signals for use in a research lab testing in advance of dose-response test execution

- Dose evaluation – use a validated model for:
  - Prediction of the dose and dose uncertainty for use directly, or
  - Prediction of the dose and uncertainty for use in a hybrid empirical-analytical dose evaluation method
  - Assessment of UAM audibility and supplemental metrics relative to the ambient soundscape.

For dose evaluation it is important that the tools employed be validated and the dose uncertainty quantified since it promulgates into the dose-response curve development. To withstand international technical scrutiny (especially since UAMs are a new source, and familiarity with UAM operational noise modeling is limited), acoustic monitoring should be included in dose-response testing near participant residences because of the newness of the UAM noise and the immaturity of noise modeling.

2.4.2.1 Tools

Readiness of Modeling Approaches

BRRC agrees with NASA that a combination of tools will likely be required. Considerations for selecting an appropriate model will depend on the fidelity and accuracy needs: lower for site evaluation during the planning and development of a recruitment strategy, and higher for use with the dose calculation method.

Tool Development

BRRC concurs that no existing recommended international standards are applicable to helicopter or UAM community noise modeling.

Tool Validation

The scoping document needs to differentiate between the three model validation elements (propagation, source, and operational modeling strategy).

Differentiation between the three modeling elements is necessary.

- The propagation model: mature area with minimal development required.
- The acoustic source data: NPDs, or spheres, or first principles calculations along with the inclusion of environmental effects to prescribed vehicle motions.
- The operational modeling strategy: fidelity requirements for operational inputs and computational strategy for cumulative exposure.

Each of these elements needs to be developed, tested, and validated.

2.4.2.2 Data

BRRC encourages NASA to explore procedures for deriving and transforming limited measurement data with application to modeling results, source data approximations and surrogate data substitution including hybrid analytical-empirical data development techniques.

Regarding the acceptance of prediction-based data in lieu of measurement-based data, BRRC thinks prediction-based data is prudent for test design and research activities, but the eventual dose evaluation will necessitate data derived either from the combination of measured and modeled data for the dose estimation or be based on empirical measurements. Some potential data concept research questions are noted in the Dose-Related Activities section.

2.4.2.3 Ambient Soundscape Characterization

Develop appropriate measures for quantifying the statistical structure of the ambient soundscape environment where people reside.

Ambient soundscape data is needed for a multitude of activities from dose-response test planning to evaluation of dose metrics. Ambient data is also needed for use in the technical challenges for everything from model assessment, monitoring technology evaluation, and testing, to use in lab and listening tests. In evaluating the influence of the ambient environment on human perception, it is useful to quantify the environment statistically. The influence of the ambient environment on human perception, principally how well the sounds of UAM vehicles blend into the background soundscape must be explored. The concept that noise intrusions are 'discounted by the background noise' is an oft-applied technique for quantifying human response. As Fidell noted (1988), residents of a given neighborhood become familiar with the statistical structure of the noise distribution in their homes. Their familiarity with the statistical characteristics of this distribution allows them to determine a reasonable criterion for "intrusive" noise events.

2.4.3 Noise Monitoring

The NASA scoping document notes that community tests will include some noise monitoring to compare dose measurements with the dose estimated by the analysis tools. BRRC agrees that monitoring is vitally important, and data gathered during the noise monitoring periods will provide a wealth of information including for characterization of ambient sounds in the vicinity of residences. BRRC suggests that monitoring data be used in a hybrid dose evaluation process.

It is anticipated (Thai, 2025) that the sounds from future passenger-carrying UAM vehicles will be barely perceptible[*] within an urban ambient soundscape. The quantification of the DNL metric (be that via modeling, measurement, or a hybrid technique) will potentially yield a limited range of independent values for development of a dose-response relationship. DNL is based on an A-weighted Sound Exposure Level (ASEL) computed by integrating the energy of the event within 10 dB of the maximum level with sufficient signal-to-noise. Recent measurements of Archer's Midnight enroute, at altitudes well below the anticipated operational cruise condition, conducted in a quiet rural field suggest that capturing valid SEL metrics (encompassing time history measurements with levels 10 dBA down from the peak) will be challenging in other ambient environments. Operational modes in the vicinity of vertiports are louder but come with

[*] Joby aircraft max level in hover is 55 dBA at 100m. https://www.youtube.com/watch?v=GHmXR0wBOiI

considerably increased complexity in terms of predictive modeling, with likely louder ambient levels and potentially lower prevalence residences nearby.

2.4.3.1 Requirements Definition

The NASA scoping document identifies the need to define requirements surrounding the purpose and type of measurements, as well as potential supplemental data to be collected. BRRC emphasizes the importance of clear definitions to maximize the value of collected data.

In addition to the items listed within the NASA Scoping document, BRRC suggests highlighting the following items for consideration:

Need and Type of Acoustic Measurements

- Specify that a range of vehicle configurations within UAM classes may be required (number of rotors, capacity, etc.)
- Specify that a range of vehicle operating conditions may be required (cruise, takeoff, transition, landing, etc.)
- Stipulate required sampling rates, dynamic range, microphone frequency response
- Standardized data format for comparison across measurement campaigns

Auxiliary Data

- Determine the minimum temporal and spatial resolution for aircraft operational data to support source characterization and modeling
- Evaluate the need for ground-based vs. stratified meteorological data

2.4.3.2 System Evaluation and Development

Development of a noise measurement and monitoring strategy for the FAA dose-response test should be prioritized and noted in the scoping document facilitating identification of opportunities for combined in situ acoustic testing.

As the NASA scoping document indicates, a wide spectrum of acoustic components and systems may be developed or leveraged based on the performance requirements of the eventual noise monitoring.

The complexity of designing purpose-made hardware and associated requirements is further compounded by the various test designs that may be needed throughout the research effort. During early phases of UAM acoustic testing, the measurement design will likely focus on individual vehicles flying scripted trajectories to facilitate source characterization and model validation. Standard acoustic testing techniques for acoustic source definitions typically involve high channel count within a relatively localized area under highly controlled conditions. Later phases will be driven by dose-response acoustic testing for a larger number of events of operational vehicles. The dose-response testing will likely involve individual channels distributed over a larger area.

To the extent possible, BRRC recommends leveraging existing systems and noise monitoring standards to reduce complexity of system design and requirements definitions. See below for a list of existing hardware, standards, and monitoring systems that may be used to inform requirements, serve as a turnkey instrumentation solutions, and potential sources of data:

Customizable Recording Systems
- X-59 GRS System
- BRRC Sonic Boom Monitoring Equipment

Turnkey Recording Systems
- Sound level meter systems with at least 1-second recording

Relevant Data Sources
- Long-term airport noise monitoring (e.g., LAX, JFK)

Standards and Best Practices
- NASA UAM Measurement Protocol (Pascioni et al., 2024)
- ANSI/ASA S12.75-2012 Jet Flyover Standard (ANSI, 2012)

2.4.3.3 Signal Processing

BRRC agrees with the scoping document. However, we believe that this task will require significant research to develop the proper validated signal processing methods.

2.4.3.4 Placement

BRRC recommends that the placement strategy be considered within the UAM dose-response test design process, and not as a broad research and technology development effort.

BRRC concurs with the placement considerations highlighted by the NASA scoping document. Practical considerations may also include recommendations for pre-test site visits to determine site suitability, weather considerations, and equipment maintenance tempo.

As discussed in Section 2.4.3.2, test design will be highly dependent on the phase of testing and the stated objectives of the specific measurement (e.g. source characterization, community dose-response, etc.).

2.4.4 Metrics

BRRC suggests NASA include modeling metrics for dose evaluation.

Dose-related metrics can be considered to fall into two categories: single events and cumulative exposures. Single event metrics provide a numerical acoustic description of the individual sounds received at the points of interest (be it weighted, integrated, etc.). Cumulative exposure involves methods to accumulate those individual sounds over a time period of interest. Considerations for aggregating the noise to obtain the dose and metrics for different numerical acoustic descriptions of the individual sounds are covered in this section.

2.4.4.1 Consideration of Duration and Number of Events

BRRC agrees with NASA's points about 24-hour dosing and variability considering ambient and suggests that NASA add another element to the scoping document under Section C.i.: Will dose metrics that utilize the subset of a 24 hour period when the participant is at home, (hence reflect their personal noise exposure - not their home address exposure) facilitate determination of appropriate time scales of interest in the context of a non-steady operational tempo?

The most accurate method of establishing a dose would be for each participant to wear a dosimeter which would evaluate their aviation related noise exposure while they are at home. Since development and readiness of such technology for public deployment is not feasible within the three-year technical challenge duration, one must rely on other methods for obtaining the dose.

The NES survey question asked for annoyance “thinking about the last 12 months or so, when you are here at home.” The dose was computed at participants homes based on as-flown aviation operations for each day over a year using the AEDT model and then averaging them to obtain an average daily DNL. This process was accomplished without knowing or accounting for exactly when the participants were at home (as has been the custom for long-term annoyance). In the dose-response relationship, the dose was a prediction, accumulation of 100% of the sound their residence received (using energy addition) from aviation noise sources over the survey year, then averaged to obtain an average daily dose. In other branches of the US Government, policies related to land use planning, which also rely on dose-response relationships, are often based on alternate dose formulations such as the DoD average busy day or the Federal Highways use of “worst noise hour” or the “worst traffic noise impact for the design year” as was described Section 2.2, Objectives Item 3.

Long-term responses over one year, if the recommended ISO/TS 15666:2021 (ISO, 2020) standard is being followed, are already somewhat decoupled from the annoyance judgment in that they are relying on the individual to uniformly assess exposure over the year while not being influenced by more recent events. The method for computing the dose should be granted some flexibility to explore alternate methods in addition to the DNL based on an annual average day. The NES dose could be reevaluated in a multitude of ways other than average daily DNL as was already described. It can also be computed using other metrics than A-weighted. For example, the Noise Exposure Forecast (NEF) is based on EPNL and is used for airport noise assessment land use planning in Canada[*].

Humans are not good energy integrators of sound, especially over the long term. The possibility of participants being more strongly influenced by recent events should be given strong consideration for UAM, if there might be changes (especially increases) in the operational tempo “at home.” The survey question duration (e.g., thinking about the last 12 months or so) should be coupled with the method of computing the dose.

The generalized cumulative noise exposure metric (Vaughn et al., 2024) is a concept for assessing the relative importance of level, duration, and number of events rather than providing them equal weight as is the case for computation of energy-based metrics. This technique can represent other factors such as the loudest, the operational tempo, and the most recent event. The formulation parameter “b” represents a sliding scale between maximum levels on one end, equal energy summation in the middle, and number of events on the other end. This metric shows promise for assessing the importance of these factors[†]. If a zonal testing approach is exercised in the eventual dose-response test, it will be interesting to see if there is difference between the vertiport zone and the enroute zones in terms of the “b” factor.

[*] Transport Canada, https://tc.canada.ca/en/aviation/operating-airports-aerodromes/managing-noise-aircraft/noise-exposure-forecast-related-programs

[†]The number of events (NA) Number of Events (at or) Above a Lmax of 50 dBA (or NA50 Lmax), was examined in the NES (Miller ,2021) as a surrogate for “noticeability.”

2.4.4.2 Considerations for Other Metrics

BRRC supports the inclusion and evaluation of other metrics beyond DNL in the NASA technical challenge. Considerations for NASA from other areas of dose-response are noted below.

Assessing the Surprise Factor

Is the "surprise" effect a concern for eVTOL operations? What about if Line of Sight (LOS) is blocked (e.g., in an urban setting) and then the vehicle is rapidly 'exposed' and audible? Is there an onset rate annoyance analogy where suddenly one can see and hear the UAM with limited acoustic warning?

There is a body of work funded by the US Military for military training routes (MTRs) that developed a DNL metric penalty for high onset rate operations (expressed when 15 dB increase per second exists) on perceived annoyance (Harris, 1989; Plotkin, 1986, 1987, 1991; Stusnick 1992, 1993). The high onset rates of the aircraft sound seem to create startle or surprise and contribute directly to the observer's perceived annoyance. The primary noise metric is onset rate-adjusted monthly day-night average A-weighted sound level, L_{dnmr} and is expressed as a cumulate 1-month duration metric based on the month with the highest number of operations. It was developed from studies that found that an overflight's annoyance rating is dependent on the event's onset rate as well as its sound exposure level. This has been validated and refined based on a series of laboratory and field studies and has been incorporated into the RouteMap model (Bradley, 1996). The MTRs are typically categorized as visual routes, instrument routes and slow-speed low-altitude routes.

Military aircraft utilizing Special Use Airspace (SUA) such as MTRs, Military Operations Areas (MOAs), and restricted areas generate a noise environment that is somewhat different from that around airfields. Rather than regularly occurring operations like at airfields, activity in SUA is highly sporadic. It is often seasonal, ranging from ten per hour to less than one per week. Individual military overflight events also differ from typical community noise events in that noise from low-altitude, high-airspeed flyovers can have a sudden onset. The cumulative daily noise metric, devised to account for the "surprise" effect of the sudden onset of aircraft noise, is the Onset-Rate Adjusted Monthly Day-Night Average Sound Level (L_{dnmr}). Onset rates between 15 and 150 dB per second require an adjustment of 0 to 11 dB to the event's SEL while onset rates below 15 dB per second require no adjustment to the event's SEL (Stusnick et al., 1992). In urban environments it is plausible that acoustic and visual masking and shielding and a corresponding sudden line of sight to the receiver can result in a "surprise" effect which could impact annoyance.

Steady State Response

How long does it take a community to achieve a steady state annoyance response to a <u>change</u> in operational tempo? If the test site is already exposed to aviation noise (e.g. helicopters) and is already used to hearing those noise sources, is a community steady state response to changing eVTOL operational tempos achieved faster?

During the controlled exposure of helicopter annoyance study, Fields and Powell (1985) noted after removing the effects of noise level, that the daily annoyance scores increased rapidly over the first few days but only slowly in the later stages of the study. They cautioned that "studies using these types of repeated interviews should be especially concerned about reaction on the first few days of the study" and noted that their analyses suggest that the study day variable should be considered in the design of future tests.

2.5 Response-Related

Feedback on the scoping document response-related topics follow in the areas of Analysis Methods and Tools (Section 2.5.1), Survey Methods (Section 2.5.1.2), and Metrics (Section 2.5.3).

2.5.1 Analysis Methods and Tools

An operational scenario analysis task, not included in the scoping document, should be added.

NASA should prioritize an Operational Scenario Analysis (Section 5.1) to develop realistic UAM operational parameters for the projected future. This analysis needs to include sufficient granularity to understand the scope of planned UAM operations. Operational parameters include corridors, numbers and cadence of operations, flight profiles, and percentage of mixed configuration types. These parameters need to be defined for both vertiports and enroute community locations under consideration for the response surveys, which will inform FAA efforts to develop a nationally representative long-term dose-response relationship.

2.5.1.1 Differences Across UAM Configurations

BRRC thinks that this question is not necessary from the response perspective and suggests that the survey question be worded in such a way as to not differentiate between different UAM configurations. Metrics should be equally applicable to all locations with UAM operations.

Differences across UAM configurations will affect the dose evaluation due to variations in operating states and source noise emissions, but it remains to be seen if metrics need to be tailored to address different vehicle types. When considering the NES and prior dose-response relationships, they used the same metric for all aircraft configurations, including commercial fixed-wing, helicopters, and military aircraft. Presumably one would expect the metric to be able to adequately represent the nuances of the received sound character.

2.5.1.2 Statistical Dose-Response Modeling Methods

BRRC does not suggest any changes to the scoping document in this section.

2.5.1.3 Metanalysis Methods

BRRC does not suggest any changes to the scoping document in this section.

2.5.2 Survey Methods

BRRC suggests changes to the Survey Methods section as described below.

2.5.2.1 Study Type

NASA research should include the effects of ambient soundscape on test design and its effect on UAM annoyance judgments for people at home.

In 1998, Fields examined the historical assumption that "in residential settings annoyance with one audible noise (e.g., aircraft) will be reduced in the presence of another noise (e.g., road traffic)." Fields' direct reanalysis of prior social surveys found that "a 20 dB increase in ambient noise (95% confidence interval of 15-50 dB) has no more impact than approximately a 1 dB decrease in target noise exposure." This factor, upon which the NES study relied by virtue of the fact that it intended to replicate the Schultz curve, (and hence did not consider ambient noise in the study design) may not be the case for UAM vehicles.

While the FAA NES study (Miller et al., 2021) developed a dose-response relationship of percent highly annoyed, Fields noted (1993) of his assessment of 136 surveys, that "intrusive noise levels which are high enough to be annoying are usually high enough so that they are not usually masked, even by high ambient noise levels in the areas that are sampled in these surveys." Fields also noted that even at low noise levels (below DNL 55 dB) that the extent of annoyance of the small percentage of highly annoyed is related to noise exposure. The basis of the prior subjective response studies appears to be dependent on the lack of noise masking where audibility or noticeability is not a factor. Considering the sound quality and spectral (and tonal) content of existing flight vehicles (civil and military fixed wing aircraft, conventional rotorcraft) and the potential differences, including broadband dominated sounds of UAM vehicles in their cruise configuration, one must ask what effect the ambient environment has on human perception of UAM sounds, both indoors and out.

BRRC agrees with the questions posed in this section, but it might be useful for NASA to differentiate between responses to steady state operations and increasing operational tempos, to evaluate if there is in fact a response difference. BRRC additionally suggests that an operational scenario analysis be conducted.

As has been noted in ICBEN and ISO 15666 standards, the survey time question should ask about the response over the past year. The stated NASA objectives indicate a desire to facilitate comparison with NES and other studies. It may be that a shorter time than one year can be utilized for UAM operations, because it is unclear if a steady state operational level will be achieved in the near term and will be sustained over a full year when the surveys are conducted. In Section 4 BRRC discusses our preferred future UAM dose-response testing approach which includes a longitudinal study to assess variations in annoyance rates for a specific survey population sub sample over the course of a year. This approach could potentially provide insights into the dose-response relationship over what could be periodically increasing operational levels*. With only a three-year technical challenge duration, and testing starting in the 2030 timeframe, it is not feasible to include a longitudinal daily dose-response study in the research phase to assess this 'steady state' response question, rather BRRC recommends it be coupled with the long-term dose-response testing. This testing is discussed in Section 4.8.

2.5.2.2 Survey Mode

BRRC suggests clarifying the nomenclature of the recruitment response rate versus survey response rate in this section (even though they were one and the same for NES). This clarification will account for potentially different testing dose-response strategies that might involve administration of multiple longitudinal style surveys.

Response rates from phone surveys have decreased as prevalence of cell phones has increased. Recruitment for QSF18 was conducted via mail and X-59 includes a mailing-based recruitment

* This assumption is based on our judgement of the reported future UAM industry actions. The recommended operational scenario analysis described in Section 5.1.1.1 can provide insights.

strategy too. These sonic boom projects recruited people for a one-month duration, and participants filled out single event and daily surveys via a smart phone app and online web browser. NES had 40%, and QSF18[*] had 6.2% recruitment response rates. WSPR recruitment was closely coordinated with the Edwards Air Force Base Public Affairs personnel to reach out to the community of residents using a range of media (email, hard-copy letters mailed to homes, news articles and advertisements, printed flyers, website postings, and other social media announcements as well as personal outreach to organized groups), so it is not directly comparable.

2.5.2.3 Survey Questions

BRRC does not suggest any changes to the scoping document in this section.

2.5.2.4 Sampling

Recommendations for changes to the sampling section are described below.

Sample Size Considerations

BRRC does not suggest any changes to the scoping document in this section.

Site Selection and Eligibility Criteria Development

BRRC recommends that this section be generalized to not suggest extrapolation/ repropagation. A general question inquiring about methods for site selection considering potential recruitment stratification and eligibility and exclusion criteria should be noted (beyond the section title).

Considerations for site selection must include the expected noise levels so that a stratification plan can be developed. For example, during QSF18 due to the specific low boom dive maneuver, differing boom exposure levels were expected in different geographic regions. Recruitment took the noise contours into account. The NES study utilized airport noise contours to develop the recruitment stencil and included DNL brackets: 50-55 dB, 55-60 dB, 60-65 dB, 65-70 dB and over 70 dB. Based on the UAM operational projections noise contours should be considered when selecting which UAM sites should be chosen, and which residential areas to select for recruitment.

Considering that the objective of the dose-response study is to evaluate subjective response "at home" one must ask what is the propensity of homes in the stratified noise? Are there sufficient residences close enough to vertiports (given current land use and vertiport placement guidelines) that one could acquire a sufficient subject pool in the higher UAM noise DNL brackets?

The Scoping Document asks about methods to correlate simultaneous noise measurements with survey results (e.g. extrapolate / repropagate measurements to surveyed observer locations). BRRC suggests that a Kalman filter approach (described in Section 5.2.5) provides an alternative method for utilizing noise measurements in conjunction with modeling to obtain the UAM doses at participant residences.

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[*] Recruitment was halted once the number of eligible participants were reached. Had it been permitted to continue, the QSF18 recruitment response rate would likely have been higher.

Combining Data from Multiple Noise Sources and Communities

Development of local geographically individualized dose-response relationships is not likely to be fruitful. How to determine the number of test sites and identify the appropriate methods for selecting and combining them into a nationally representative sample should stand as a question on its own. Separation of dose-responses by UAM aircraft category is not consistent with the objective of developing a nationally representative UAM dose-response relationship. The topic of data combining also fits into the metanalysis section.

In this section NASA brings up the topic of local geographic deviations in dose-response from the national average. It is not clear what the intent is. Historically policy at the Federal level has been set in a uniform manner with criteria based on consistent objective metrics, without any adjustment for local regions. BRRC does not believe that pursuing the Community Tolerance Level (CTL) (Fidell, 2011) is appropriate for policy making as it is not a standardized function, it is however a useful mechanism to quantify differences between communities via differences in the CTL level. The reason such metrics shouldn't be used for policy is because the CTL is not a predictive tool, rather it is evaluated from acquired dose-response data. It has been demonstrated that about only one-third of variance between respondence annoyance is explained by noise alone and the remainder is due to non-acoustic factors. A literature review documented in the ACRP study (2014) noted 62 factors "other than the acoustical characteristics of the noise source" which have been hypothesized to affect annoyance with noise. CTL might help quantify these non-acoustic factors, but at present we are not aware of methods to obtain CTL a priori.

In our preferred approach, we suggest that the FAA NES dose-response test include ten survey sites selected using a balanced sampling approach. It can be difficult to develop a "nationally representative" dose-response curve from a small number of communities. If the results are too different across communities, they will not combine in a statistically rigorous sense. In 2030, will there be enough UAM operational locations? If there are only a few communities, is it even possible to combine them in a nationally representative dose-response curve? BRRC agrees that this is a valid question.

The scoping document notes that the UAM aircraft will have more variation than that in the large commercial transport aircraft. While this is true, BRRC notes that the DNL metric is also used for other transportation modes including helicopters, military jets, highway, and rail noise, and is combined with aviation noise for multimodal projects. In fact, the NES study included both helicopter and military aviation contributions to the DNL evaluation. Since the noise environment and background are to be assessed together, BRRC does not feel it necessary to separate the UAM aircraft types because of the variability in their signatures. Additionally, US companies are converging either to vectored thrust (Joby, Archer) or lift plus cruise (Beta).

Screening and Disqualification Criteria

BRRC recommends adding screening and disqualification criteria as a new section under survey methods in the scoping document.

During the QSF18 project a significant amount of attention was paid during site selection (Page et al., 2020, Appx. A) to evaluate the prevalence of local issues and develop screening items and disqualification criteria (e.g., recent aviation noise related lawsuits at nearby airports or military installations and active FAA metroplex or airport flight track redesign or expansion activities). For UAM dose-response testing, screening criteria development will also be important, however the relevant factors are likely to be different. For QSF18, areas with active metroplex changes were avoided to reinforce that field test participants are responding to the low boom noise, and not to recent changes in commercial aircraft overflight noise, to ensure the integrity of the survey response data. If respondents are still adjusting to the new sounds due to changes in airport noise, the ratings for UAM vertiport or enroute noise may be influenced by attitudes that are a result of the airport noise. Findings will likely be more definitive in areas without recent changes in aviation background noise.

2.5.3 Metrics

2.5.3.1 Alternative Response Metrics

BRRC agrees that other response metrics should be considered in the testing of community response to UAM noise.

2.5.3.2 Laboratory Studies

NASA has itemized the upcoming planned laboratory studies. BRRC has noted some additional objectives below for consideration.

UAM vs. Helicopter Annoyance

BRRC suggests rewording the scoping document to reflect "how" (not if) studies can be conducted in mixed operational environments.

When considering the future FAA nationally representative dose-response test, it is unclear if it will be desirable, or indeed even possible, to only survey areas exposed to UAM noise in the absence of helicopter operations. The NES test included helicopter operations as well as military flights. BRRC concurs with this test but suggests that the test objectives incorporate a survey instrument test component (if not already included) to verify appropriate survey language that asks the participant to differentiate their annoyance response between UAM and helicopter sounds. Comparison of results with Mestre (2017) should be considered.

UAM vs. Small UAS Annoyance

BRRC suggests rewording the scoping document to reflect "how" (not whether) studies can be conducted in mixed operational environments.

The ubiquitousness of sUAS (including hobbyist UAVs) might make it challenging to identify survey regions for the future FAA dose-response test without them, and one might question the effect of doing so in a recruitment design on the national-representativeness of the eventual dose-response relationship. Understanding the public's ability to differentiate these sounds is important. As was noted above regarding UAM vs. helicopter annoyance, structuring the test to also act as a test of the survey instrument (if not already included), to identify suitable language is important.

Noise and Number

BRRC suggests that the scoping document include consideration of the effect of operational tempo for UAM flights in corridors on annoyance. BRRC also notes the need to more directly relate noise and number testing in a laboratory setting to future long-term at home annoyance.

BRRC agrees that testing perceptive elements related to the level, frequency and number of operations is important. Christian (2023) and Vaughn (Vaughn et al., 2024) have shown that the number of events has a greater impact on the response than expected based on the principle of equal energy. They suggest that a change in the annoyance response occurs if the flight cadence is between 0.5 flights per minute and 2 flights per minute, "which seems to coincide with the transition from an impression of discrete (but frequent) sounds to a constant (blended) sound" (Christian, 2023). It has been hypothesized and reported in the Noise Policy Review Docket (FAA, 2024) that NES results which showed increased annoyance at lower levels of exposure could be due to the FAA NextGen airspace modernization resulting in impacts in communities unaccustomed to overflights. One may speculate if the trend observed by Christian and Vaugn is also applicable to NES data especially in concentrated NextGen corridors where the reduction of aircraft dispersion and narrowing of flight tracks has yielded a higher cadence of overflights for some communities.

A laboratory setting test structured to assess annoyance to different combinations of events and cadences with varying loudness levels and number of operations and ideally ambient sounds will provide insights, specifically related to the generalized cumulative noise exposure metric (Vaughn et al., 2024). It is unclear how a laboratory test with limited time duration will directly relate to a future NES-like long-term annoyance survey. However, an "own-home" hybrid test will help to answer the time duration and number of events aspects of the long-term UAM noise exposures. This type of test would follow the approach of the USAF sponsored "own-home" study on the effect of low-altitude, high-speed overflights (Stusnick et al., 1993). This study utilized audio playback systems within each participant's house to play audio signals at various levels and tempos. The participants completed daily questionnaires. This approach can address duration and numbers in a controlled manner that allows these parameters to be evaluated.

Ambient Noise

BRRC agrees that the effect of ambient noise is an important parameter to be investigated to inform the site selection for the UAM study.

Remotely Administered Tests

BRRC agrees that remote tests may be an efficient way to evaluate perception parameters and variability of community responses across the country and outside of the US.

2.5.3.3 Early Field Test Opportunities

BRRC suggests that "Early Field Test Opportunities" be moved to Section 6 "Other Activities" due to broader applicability than just metrics or response related matters. The Osaka World Expo is outside the timeline of the recommended activities and should be removed.

Reporting indicates[*] that the UAE has initiated the development of aerial corridors connecting airports with other places in the UAE to "ensure seamless integration of piloted and autonomous air taxis and cargo drones." Both Joby and Archer have been flying in the UAE and have issued statements that they intend to start commercial operations in 2025 or 2026. Public details are limited, but monitoring for measurements of opportunity could yield fruitful data and insights.

The timing of the Los Angeles 2028 Olympics is ideal, provides data gathering opportunities and appears as a key milestone in many of the activities described in Sections 5 and 6.

2.6 Other Activities

2.6.1 Coordination

The scoping document should note that the Advanced Acoustic Model asset is owned and managed by Volpe. International coordination should explicitly include the ICAO CAEP Modelling and Database Group (MDG). BRRC recommends adding a new coordination group called "Technical Groups" that includes technical societies and OEMs.

Although the introduction to this section notes that coordination with stakeholders should also happen, it does not specifically address which stakeholder groups or the modes of coordination. BRRC thinks that the NASA ATWG and UNWG meetings and the subgroup periodic meetings are directly relevant groups and should continue to be engaged.

While many OEMs are already involved with UNWG, it would also be prudent to directly engage UAM operators. Under International Coordination OEMs are called out regarding demonstrations and operations outside of the US, but a similar coordination should be encouraged within the US as well.

In addition to the standards organizations, professional organizations such as Vertical Flight Society (VFS), Acoustical Society of America (ASA), and the American Institute of Aeronautics and Astronautics (AIAA) provide mechanisms to disseminate information and garner relevant information about concurrent research and provide feedback.

2.6.2 Standards and Guidance Development

BRRC recommends that NASA proactively identify relevant and applicable existing standards and guidance documents and suggest which should be expanded and what gaps should be filled by newly created standards and guidance documents. Elements of the standards could be incorporated into NASA technical challenge research and activities.

2.6.3 Community Engagement

No scoping document updates are needed.

2.6.4 Technical Reviews

No scoping document updates are needed.

[*] https://www.businesswire.com/news/home/20250213996930/en/UAE-Begins-Mapping-Air-Corridors-for-Air-Taxis-and-Cargo-Drones-to-Transform-Urban-Transportation

3 ALTERNATIVES

Alternative ideas that BRRC thinks NASA should also consider are described in this section, including:

- Descriptions of other modeling tools in use by the Federal Government and Industry,
- Federal treatment of other transportation sources,
- Operational tempo and concurrent noise signals,
- An alternate dose evaluation method, and
- A case for considering non-acoustic factors.

3.1 Alternative Modeling Tools

Within the US, DoD tools such as NoiseMap (integrated) and AAM (simulation) are used around airbases for fixed and rotary wing operations, while analysis of noise from Military Operating Areas (MOAs) and Military Training routes (MTRs) uses the MRNMap tool. Models, such as Traffic Noise Model (FHWA, 2023) and SoundPlan[*], have additional features and could potentially be exercised to account for insertion losses due to natural terrain, buildings, and structure and building reflections, which is important for urban environments. ISO 9613-2 (2024) documents a general method for effects of barriers, reflections, and manmade structures. The NORD2000 model has algorithms for diffraction from terrain and barriers (Plovsing, 1994).

Sophisticated features can be incorporated into noise predictions by applying the principles of linear acoustics. The use of a blended method, applied to an integrated model, as portrayed in Figure 2 has been recommended for AEDT (Downing et al., 2019) for modeling terrain and manmade structures via adjustments[†]. This approach was also recommended for use specifically with helicopter modeling for AEDT (Page et al., 2015). Linear superposition could also be used to account for the impact of cylindrical divergence from line sources rather than spherical divergence from point sources if warranted based on the operational tempo.

[*] https://www.soundplan.eu/en/software/soundplannoise/current-version

[†] Adjustment is the terminology used in the AEDT documentation to apply changes to the pre-propagated NPD values, such as absorption changes for non-reference meteorological conditions and lateral attenuation and vehicle lateral directivity changes based on elevation angle and slant range.

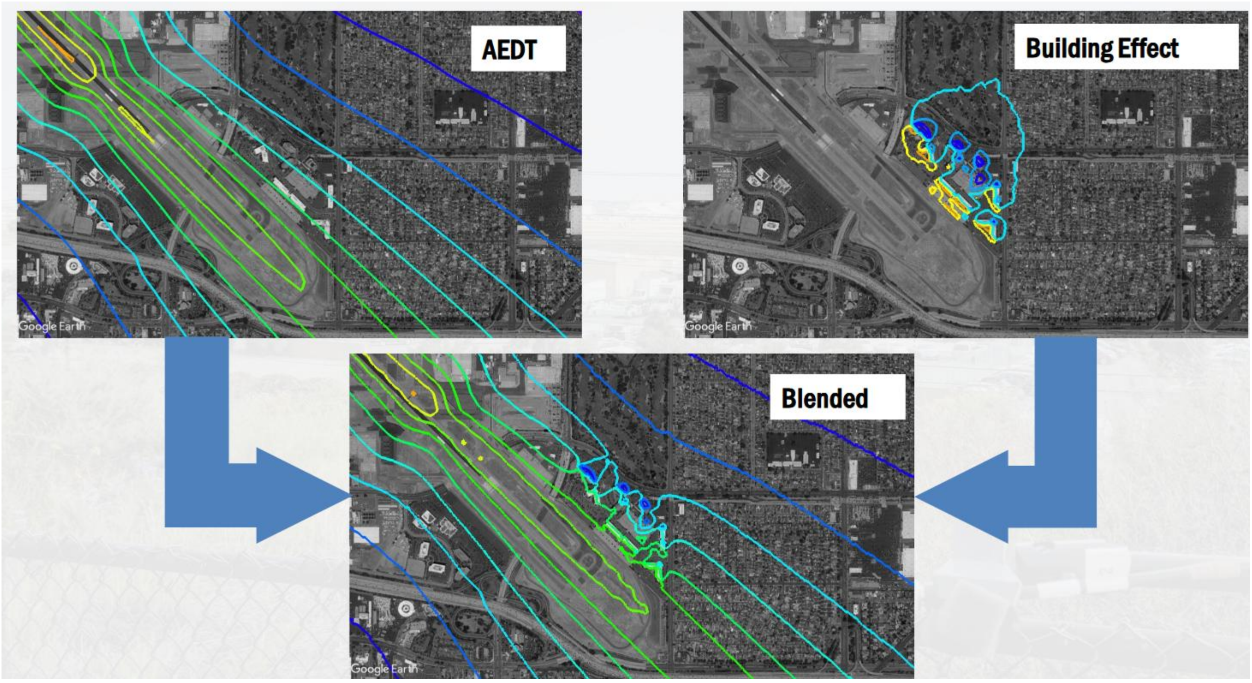

Figure 2. Blended Method Calculation for an arrival at LGB. *(Source: Downing et al., 2018)*

Simple methods such as the NCHRP Barrier Reflections Screening Tool (Bowlby et al., 2018) provides an efficient estimate for regions where reflections from barriers can elevate noise levels. It was modified for application to airport noise for airport planners to screen for potential reflection effects outside of the FAA AEDT model. This kind of tool could be applied at potential dose-response locations using operations forecasting data for UAMs to estimate those effects on the noise levels in the communities and the relative importance of addressing them in the eventual dose-response estimation process.

Source Modeling: Point vs. Cylindrical Source

The FAA has described under the umbrella of NextGen, their future UAM Concept of Operations (FAA, 2020) which describes UAM Airspace with operations initially in corridors. The document notes that within corridors strategic deconfliction and tactical separation occur without direct air traffic control involvement. They have envisioned performance-based criteria that will enable increased operational tempos without the need for tactical ATC separation services. The burden is on the stakeholders to plan, manage, execute and oversee UAM operations within the corridors. The ConOps document does not contain any projections of the rate at which the operational tempo will increase and what can be expected but nods to regulatory evolution and UAM corridors that leverage collaborative separation methodologies. Considering the future operational tempo, Section 6.1 describes related activities. It could be necessary that divergence modeling in the tools needs to consider point versus cylindrical sources (an attenuation of 3 dB vs. 6 dB per doubling of distance) as is used in highway and railway noise modeling (Figure 3).

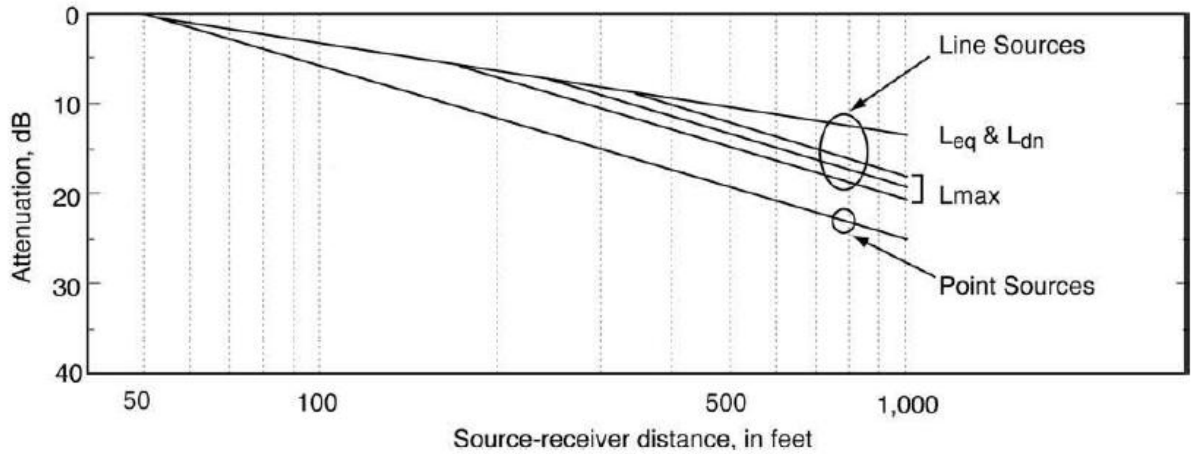

Figure 3. Attenuation Due to Distance (Divergence). *(Source: FTA, 2018)*

3.2 Federal Treatment of Other Transportation Noise Sources

Other federal transportation agencies have different criteria, metrics, and analysis procedures established. For example, the Federal Transit Administration (FTA) guidance manual (Quagliata et al, 2018) presents methods for assessing noise and vibration impacts of proposed transit projects using the DNL (dBA) and worst noise hour $L_{Aeq,1hr}$ (dBA) metrics. It describes criteria for evaluating no, moderate, or severe impacts for new sources of transit noise and for changes to existing transit noise for different land use categories (e.g. residential, institutional, and high sensitivity areas). The FTA also applies $L_{Aeq,1hr}$ for institutional land uses, relevant to projects that include multiple modes of transportation. The use of worst hour $L_{Aeq,1hr}$ may have application to UAM operations along corridors since they are similar to road traffic noise exposures.

3.3 Operational Tempo and Concurrent Noise Signals

If the operational tempo is high enough, measured time histories may contain simultaneous recordings of multiple aircraft and not individual events. Computing SEL and other metrics from overlapping operations can be nuanced.

BRRC has conducted several DoD sponsored community noise model validation studies for NoiseMap and AAM (Downing, 2022; Navy, 2021). In many instances, DoD operations include multiple aircraft flying in formation, resulting in overlaps and distinct peaks in the time histories without a “clean” signal within 10 dB of the maximum. In these military training situations, the squadron includes the same vehicle type, operating under similar conditions in close proximity. This permits the assumption of equivalent noise source levels; hence one can apply a simple energy subtraction method. In the example provided in Figure 4, the computed SEL for an entire event with two aircraft is reduced by 3 dB and assigned to each operation for the purposes of noise model validation.

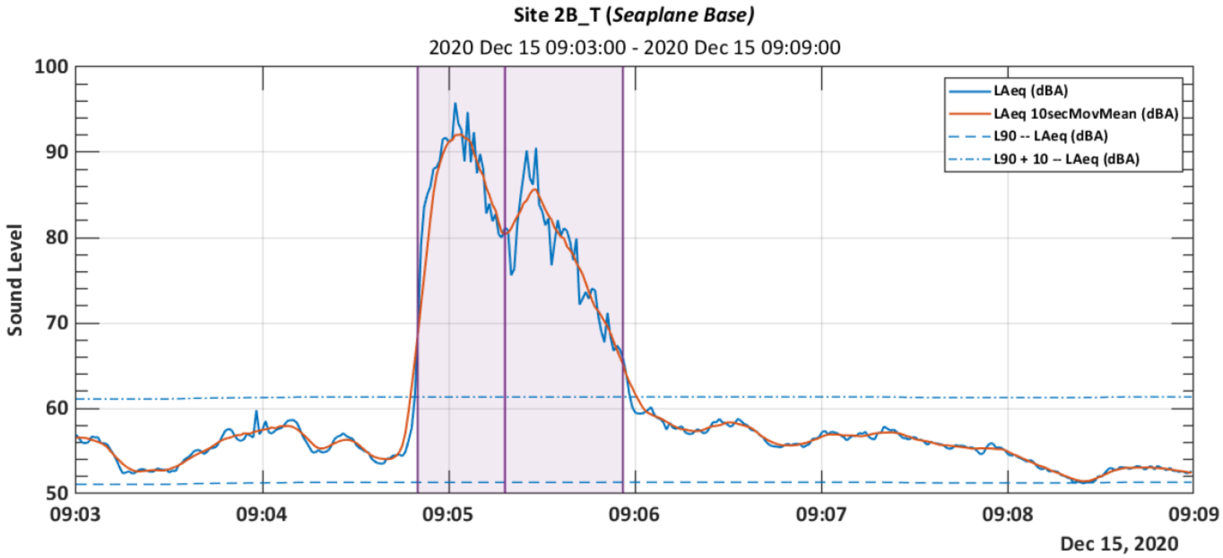

Figure 4. Measured Time History for Two Navy Aircraft *(Source: Downing et al., 2022)*

Some measurement technologies, like phased array measurements, can be used to distinguish multiple sources if (1) the sources are spatially distributed and (2) the geometry of the phased array supports source separation for a given scenario. For example, a vertical line array can be useful to discriminate land-based noise sources from airborne sources (assuming sources are not at grazing incidence). This would allow for more meaningful measurements in the air. However, multiple concurrent airborne sources are not as easily separable from a vertical line array geometry. NASA should consider the need for measurement techniques that allow for distinguishing between multiple sources (land-based, airborne, and mixed). In addition, there will be scenarios (as identified in the Navy aircraft example) where the eVTOL noise is inseparable for multiple aircraft. During the noise monitoring period described by NASA, what considerations are needed if one of the vehicles is an eVTOL and another a fixed wing jet or helicopter or a different model (or operating condition) UAM vehicle?

During the NES study, some of the recruited participant homes were also in the vicinity of military bases. The noise exposure from those aircraft operations were computed and included in the projected NES dose. It is possible that the future UAM dose response testing will also include regions exposed to noise from military operations. As is often the case for DoD operations, only one of the aircraft flying together has their transponder activated. This results in the operation showing up on radar tracking systems as a single aircraft, whereas it most likely represents multiple aircraft. During the BRRC Navy monitoring project, DoD tower records (manually logged during the monitoring period) were used to obtain the actual number of aircraft flying together for each operation. A similar or alternate procedure might need to be employed for the future UAM dose-response monitoring (see also Section 2.4.3.3).

3.4 Alternate Dose Evaluation Method

The NASA Quesst mission is employing a hybrid dose estimation method using a Kalman filter for quantifying the low amplitude sonic boom dose that was developed by BRRC (Lympany & Page, 2022). The process begins with two sources of noise exposure data: the noise exposure calculation (on a grid across the region of interest) based on modeling and the noise exposure measurements (at specific monitoring locations in the region of interest). The noise estimation process combines the measured and calculated noise exposure to obtain the dose and an estimation of dose uncertainty at participant locations. This method is flexible and can be applied to a multitude of metrics including ambient related metrics. Additional description about the Kalman method is provided in Section 4.5.

3.5 A Case for Considering Non-Acoustic Factors

Non-acoustic factors have been shown to account for a large portion of the variance in annoyance (discussed in Section 2.2, item 5) but have not been listed as an objective in the NASA scoping document. BRRC thinks it is worth exploring the research potential of using short-term dose response to evaluate the effect of non-acoustic factors on annoyance.

As noted by Fields (1985), the "main significance is the finding that attitudes do affect these short-term annoyance judgements in much the same way that attitudes have been found to affect long-term annoyance judgements in other surveys." Fields does note that non-acoustic factors are "of relatively little practical importance for predicting annoyance" since attitudinal data is not available for planning purposes. These factors can be used to explain at a portion of the variance in the dose-response relationship.

Prior researchers have categorized non-acoustic factors in different ways. DNWG (2009) grouped them into two sets of variables: emotional and physical (Table 1) whereas ICAO (2024) used three categories: internal personal, external social and external physical.

Table 1. Non-acoustic Factor Categories (DNWG, 2009)

Emotional Variables	Physical Variables
Feelings about necessity/preventability of the noise	Type of neighborhood
Judgment of importance/value of the activity that is producing the noise	Time of day
Activity at the time an individual hears the noise	Season
Attitude about the environment	Predictability of noise
General sensitivity to noise	Control over the noise source
Belief about the effect of noise on health	Length of time an individual is exposed to a noise
Feeling of fear associated with the noise	

In the European ANIMA[*] dose-response study (Haubrich et al., 2019) reviewed the role of non-acoustic factors in noise impact mitigation interventions and noted that attitudes to the noise source, trust, and perceived control have the strongest influence on people's annoyance levels and are the most modifiable within the scope of interventions, including communication with and engagement of relevant stakeholders such as residents. The NASA scoping document indicates that development of a strategy for community engagement (at a national, regional, and local level) during the period leading up to and during the eventual UAM dose-response testing is of interest. Given the link between non-acoustic factors and modifiable annoyance levels as outlined in the ANIMA report, methods to assess and quantify these relationships could be important to assess if local interventions (perhaps by operator advertising and marketing in future testing regions) have affected annoyance responses.

Visibility of the Vehicle Operation

The NES study results examined some supplemental metrics, including one that could be considered a non-acoustic factor, namely whether the aircraft was 'visible' at its point of closest approach to the respondent's home. The NES study reports that there is no statistically significant relationship between the dose and the response. However, more recently, and specific to eVTOL operations, the results of the Eve Air Mobility Visual and Sound Perception study (Oliveira & Aalmoes, 2025), presented at a recent UNWG SG3 meeting, suggested that there were no differences in annoyance ratings for enroute segments, with or without the sight of eVTOLs overhead. However higher annoyance ratings were found when the aircraft was visible during takeoff. Is this difference due to the vertical flight aspect of the operation, which might be less familiar, and perhaps interpreted as less safe? Over time, would familiarity with the takeoff segment of UAM operations affect annoyance?

Association of Residential Greenery with Annoyance

Researchers in Europe (Schaffer et al., 2025) recently examined the airport noise annoyance study NORAH (Schreckenberg et al., 2025) to evaluate the relationship between residential greenery and noise annoyance. They found that greenery decreased road traffic noise annoyance for DNL levels up to around 60 dB, but increased annoyance at higher DNL. For aircraft noise annoyance, the opposite was true, with the annoyance slope change at 55 DNL.

BRRC thinks that the scoping document should include non-acoustic factors and specifically explore to what extent do non-acoustic factors influence the perception of UAM vehicles?

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[*] Aviation Noise Impact Management through novel Approaches (ANIMA), https://anima-project.eu/

4 PREFERRED TEST APPROACH

The test design process requires an understanding of future UAM operational scenarios with sufficient granularity to guide the testing details. In support, BRRC laid out a skeleton of a future FAA dose-response test design to facilitate our review and development and prioritization of research activities. The key elements of our test skeleton are in Table 2 and discussed in this section.

Table 2. Skeleton Features for Vertiport and Cruise Dual Zone Test Design

Survey Type	Annual Long-term Dose	Longitudinal Daily Dose
Locations	10 across the US	3 location subset
Participants*	5000 total, 500 per test site	~200 participant subset each site
Surveys	One annual annoyance survey	Daily survey
Duration	Once	15-20 survey days
Repeats	Once	2 - 4 times based on operational tempo

4.1 Test Design Process

Although NASA has indicated that they will not be conducting a dose-response test for the FAA and conducting research to only provide scientific-based guidance, BRRC strongly recommends that NASA utilize a multidisciplinary and multistakeholder process to develop a potential test protocol. Executing a test design process and developing an eventual test plan (even if NASA does not execute it) will help to:

- Refine key questions and hypotheses that require testing,
- Identify specific analyses that are required for test-design and execution decision making,
- Note where various analytical and measurement processes are needed,
- Point to inconsequential versus influential assumptions for modeling, measurement, surveying, and analysis,
- Quantify uncertainty and develop protocols for uncertainty quantification in all steps of the testing and analysis process,
- Clearly identify necessary data for eventual test execution and dose-response relationship development, and
- Hone the RVLT technical challenges.

Operational Scenario Analysis to Support Test Design

As BRRC was considering technical activities and developing a research roadmap, it was repeatedly desired that operational scenario data existed to help guide the decision making process. This activity is not discussed in the scoping document (see recommendation in Section

* The combined sample size for NES was over 10,000 while X-59 is targeting about 5,000 or about 1,000 per test site (Rathsam et al., 2023). Modeling using the expected form of the future statistical analysis method (e.g., logistic regression and multilevel logistic regression) can be used to estimate the standard errors to evaluate sample size for the desired model precision.

2.5.1), but BRRC thinks it is important for effective test design and prioritization of research activities. A complete description of this activity is in Section 5.1.

Test Skeleton Overview

In this section BRRC describes a potential test skeleton for the future FAA-led UAM dose-response test, for the purpose of identifying knowledge gaps and research needs, and to help focus brainstorming efforts and develop consistency in roadmap planning and prioritization for a future RVLT technical challenge. As explained in Sections 1 and 2, the objective of the skeleton test design is to develop a long-term cumulative and a daily cumulative dose-response relationship that quantifies percent highly annoyed with the DNL (and metrics suitable for comparison with legacy studies) and other UAM metrics that consider the local ambient noise environment, supplemental metrics suitable for public outreach and for use in NEPA studies, and non-acoustic factors.

The testing will be conducted in different communities exposed to UAM noise, selected using a balanced sampling approach much like NES, across the United States. An activity described in Section 5.3.1, will assess if the balanced approach needs to include a factor such as the ratio of UAM operations to the remainder of the operational fleet at that location. A zonal monitoring and survey approach will be used in each community considering two zones: near vertiport and enroute.

The long-term response test will be in the form of a cross-sectional study that surveys multiple populations asking about noise over the last year. The daily cumulative response relationship will be evaluated using a longitudinal study of a subset of participants in a selected number of populations employed in the cross-sectional study. These participants will be asked daily questions about daily noise and annoyance during four separate evaluation periods with 15-20 test days per evaluation period. The combination of long-term and longitudinal cumulative daily dose-response relationships (in a subset of the long-term respondents) will facilitate understanding of the long-term dose response test results and their variability, assess the effects of non-constant operational tempos, permit evaluation of the steady state response time, identify metric thresholds for acceptance, and support other activities.

4.2 Zonal Approach: Vertiport and Enroute Areas

Our design for each community test will employ two zones: one near the vertiport area and the other exposed to enroute noise. These two zones are likely to have considerably different source characteristics and ambient conditions. Variations and overlaps are expected in the dose in these two areas based on the metric of interest (for example DNL vs. ambient based metrics). The intent of using the dual zone approach is to simplify the dose evaluation and uncertainties while ensuring a range of dose stratification categories. The near vertiport operations will be more dynamic, louder, and possibly contain different spectral content and acoustic qualities at the residence locations. The ambient sounds in these locations could also be considerably different.

4.3 Dual Testing Approach: Annual and Daily

BRRC envisions the eventual FAA directed testing to utilize a dual approach: the primary long-term dose response survey and secondary daily dose response surveys in a subset of participants.

The primary test will be a single survey evaluating long term (annual) dose-response in multiple test communities, like the NES survey. The purpose of the longitudinal daily annoyance surveys is to inform researchers on variability of responses from operational tempos increases over the one-year long-term survey question period, which is expected. This approach also provides a direct method for evaluation of other metrics.

The reason daily dose surveys areas are recommended (in addition to a usual annual annoyance question) is to develop the relationship with the actual participant daily at home dose. BRRC hypothesizes that single event responses for snapshots of time at consecutive but spaced time periods, as the volume of operations increase, will be related (albeit not directly comparable) to the long-term steady state annoyance levels. Knowing the times at which participants are at home will allow for less uncertainty in the dose evaluation than the long-term dose and can possibly provide more granularity in the projected trends.

Even though the daily versus annual responses are not directly comparable (Fields et al., 1995), trends from the daily dose responses from the multiple survey periods will provide insight. Other metrics, including supplemental metrics and those involving ambient sounds, can be more accurately estimated and applied to inform land use and environmental policies at the federal, state and local levels.

A longitudinal series of tests can be designed to recruit a small subset of the long-term dose participants (several hundred*) to provide additional daily annoyance and information about participant times at home (for the purposes of predicting the daily at-home dose). These tests should occur several times over the duration of a year (perhaps seasonally or timed based on operational tempo changes). Each of the longitudinal tests should include 15-20 survey days and engage the same people each time. The longitudinal tests should be conducted in at least three different test sites (and include both zones). Two of the areas should be expected to have a change in the UAM operational tempo during the year with the third area expected to have relatively steady operations. The longitudinal survey is intended to provide insight into the relationship between annoyance response and (via evaluation of each participant's daily at-home dose). Is the daily dose annoyance response during low, medium and high operational times the same? If daily annoyance increases (from the same participants) from one test to the other, this will give an indication of the response uncertainty to the "over the last year" long-term annoyance responses. These comparisons can illuminate annoyance trends related to a changing operational tempo.

4.4 Dose-Response Test Locations

A balanced sampling approach like NES should be employed for the selection of 10 multiple test locations across the US. Although the exact operational tempos of UAM across the country are unknown at the present time, the selection of study locations needs to consider a balanced approach within the limits of future UAM operations.

4.5 Hybrid Dose Estimation Method

The primary objective of the dose-related activities is to determine the outdoor acoustic metric(s), or dose, at each survey participant's residence. If the final product of the UAM community

* The helicopter dose-response study (Fields et al., 1995) recruited 338 residents.

response test is a dose-response curve, the dose-related activities produce one-half of the final product, namely, the independent variable of the dose-response model. At a minimum, the dose-related activities will quantify the outdoor DNL produced by UAM operations. In the preferred test approach, the dose-related activities will also quantify alternative and supplemental metrics to describe UAM and sUAS noise.

The most accurate approach to determine the dose is to deploy long-term acoustic measurement equipment at each survey participant's residence, but this approach is infeasible due to privacy, cost, and practical concerns with a large survey sample size. The preferred test approach will employ a hybrid dose estimation method that combines modeled and measured acoustic metrics to produce the best estimate of the outdoor acoustic metric(s) at each survey participant's residence. The hybrid method is based on the Kalman filter method developed by BRRC to estimate noise exposure for X-59 community response testing (Lympany and Page, 2022). The hybrid method combines measured acoustic metrics at discrete locations with modeled acoustic metrics across the entire community response area when both the modeled and measured metrics are subject to uncertainty. Additionally, the hybrid method quantifies the uncertainty in the estimated dose to support Bayesian dose-response models that account for dose uncertainty.

The hybrid noise estimation method combines the modeled and measured acoustic metrics by a weighted average across the modeled noise grid. The Kalman filter method determines the optimal weights for the weighted average based on the relative uncertainty of the modeled and measured acoustic metrics. Each modeled or measured data point, even if it has high uncertainty, conveys some useful information about the true acoustic metrics. Intuitively, data points with lower uncertainty convey more information about the true acoustic metrics than data points with higher uncertainty; hence, the Kalman filter method assigns more weight to data points with lower uncertainty. The Kalman filter method produces the best estimate of the true acoustic metrics with lower uncertainty than either the modeled or measured acoustic metrics alone.

The result of the hybrid noise estimation method is the best estimate of the dose and associated uncertainty on the modeled noise grid across the community response area. The dose and associated uncertainty at each survey participant's residence is determined by bilinear interpolation from the surrounding grid points to the residence.

4.6 Noise Monitoring and Measurements

The preferred test approach relies on noise monitoring to benchmark existing analysis tools and develop dose-response models. The primary purpose of concurrent noise monitoring is to measure the acoustic metrics associated with community response to UAMs and quantify the ambient acoustic levels within each study area.

Noise monitoring will be conducted in support of both the long-term dose-response and the longitudinal daily dose surveys. Noise monitoring data for both UAM and ambient noise will be used as input to the dose evaluation method. Requirements for each type of measurement will be defined to best meet the objectives of each approach. The placement strategy will be developed as part of the detailed test design since it will be highly dependent on situational factors. As discussed in Section 4.2.1, BRRC's preferred test design includes both vertiport and enroute areas. Thus, ambient and metric measurement strategies will be tailored to most accurately quantify the specific survey zone and provide data for the dose evaluation process*. In general, noise monitoring will consist of:

- Selection of measurement areas based on vertiport location and associated enroute areas
- Selection of measurement instrumentation
- Desktop identification of measurement sites within the study area
- Preliminary site visit for down selection of measurement sites
- Deployment of measurement instrumentation
- Blend of attended and unattended monitoring

4.7 Noise Model and Noise Modeling

Noise modeling will function as input to the hybrid dose estimation process (Section 4.5) to evaluate the dose at each participant's residence. The exact noise model and noise modeling technique will be determined based on the outcomes of the research activities and the recommendations and best practices developed before the FAA UAM dose-response test.

Noise modeling for the long-term dose response (the aggregation of operations over the duration of the survey period) for correlation with the annual annoyance ratings can be computed in a variety of ways such as average annual dose (as was done for NES) or for example based on average busy day. The daily annoyance rankings will be tailored to each residence location based on the reported times at home. If the recommendations from the response-related activity assessing the effect of operational steadiness on long-term response suggest a different duration, the modeling will proceed accordingly.

4.8 Surveys

Our skeleton test plan includes a background survey and the following annoyance surveys:

- Cumulative event survey to assess long-term annoyance
    - Single survey about long-term annoyance 'over the last year at home'
- Longitudinal daily response survey to assess daily cumulative annoyance
    - Multiple surveys about daily annoyance and times at home

The exact content and context of the survey questions will be informed by future studies and research leading to the survey testing.

The BRRC team recommends that the survey instrument specifically asks about annoyance to UAM vehicles since the stated NASA objective is to develop a UAM dose response curve. When the NES study was conducted, the intent was to gather response data to all aviation noise, not just responses to one particular vehicle type. Testing to identify appropriate survey question wording to avoid potential confusion or bias is needed. The likely UAM use cases and viable markets for operations are as airport shuttles and air taxis for which a significant portion of operations would be to and from a commercial airport. Identifying communities with only UAM operations in the absence of significant commercial airline traffic could be difficult.

* The Kalman filter method needs (1) the measured acoustic metrics of the desired signal and (2) the associated uncertainty. The uncertainty is likely dominated by SNR, so extracted signal and ambient is likely sufficient.

4.9 Sampling

Our preferred test approach is to use balanced sampling. The NES and the upcoming X-59 Quesst dose-response testing both combine dose-response results from multiple survey locations. The locations for NES were chosen using a balanced sampling approach. Similar considerations are being utilized for the X-59 testing where survey responses will be weighted based on the socio-demographic differences between the actual respondents and the profile of the study site. We recommend an activity to investigate if effects of other aviation sounds on balanced sampling factors should be included (Section 5.3.1).

4.10 Recruitment

Recruit and survey administration should be in two zones: communities near the vertiport (where UAM state is changing and noise impact is likely greater) and under envisioned enroute "corridors" where multiple aircraft with overlapping time histories will occur. A list of recruitment stratification parameters for consideration is provided in Table 3. Considering prior tests, a plausible sample size of 1,000 participants per site or 5,000 participants in total is suggested, but a statistical analysis will need to be conducted to determine the appropriate sample size per site and per zone. The NES surveyed about 500 people per airport with about 10,000 respondents in total to the mail survey. Quesst X-59 is targeting 1,000 recruits per test site for about 5,000 participants in total. The Fields (1985) daily dose helicopter study surveyed 338 residents.

BRRC does acknowledge that some of these stratification factors are correlated and overlap. However, these correlations can aid in the explanation of the final dose-response relationship.

Table 3. Recruitment Stratification Parameters for Consideration.

Noise Contours	Other Factors
DNL and other vintage metric	Day vs. evening vs. night operations
Audibility metrics	Operational tempo / cadence
Generalized cumulative exposure metric	Zone (vertiport and enroute)
Background noise discounted ASEL	Demographics
Ambient soundscape	Distance to corridor
Number of events	

5 TECHNICAL ACTIVITIES

The technical activities are described in this section. They begin with an operational scenario analysis to support test design (Section 5.1) whose outputs and deliverables are necessary for the other activities: dose-related (Section 5.2) and response-related (Section 5.3) and require coordination, standards, community engagement, and technical reviews (Section 5.4).

5.1 Operational Scenario Analysis

The principal objective of this task is to quantify future UAM operations with sufficient granularity to inform subsequent FAA efforts to develop a nationally representative long-term dose-response relationship. NES could rely on FAA flight data (as flown and air transportation forecasts), reliable projections of future UAM operations are more uncertain. This information is vital for developing the UAM dose-response test. Understanding the scope, timeframe, and growth rates of future operations also has implications for assessing technology needs and prioritizing activities. The results of the operational scenario analysis will refine the eventual research roadmap and inform the NASA UAM technical challenge.

Key Outcome: Activities are designed to produce for the FAA UAM dose-response testing timeframes under consideration 1) projected operational scenario data summarized in Table 4 using 2) a standardized database structure.

Table 4. Operational Scenario Data Elements

Operational Element	Description
Vertiport Locations	Locations where sustained UAM operations occur. Identify ground / rooftop landing pads.
Vehicle Types	Fleet mix and specific models at each vertiport.
Flight Trajectories	Describe tracks / profiles / operating states. Identify takeoff & landing / cruise regions. Quantify route dispersion.
Operational Tempo (Nominal)	Quantify hourly, daily and seasonal variability and day vs. night operations. Quantify meteorological impact on preferential vertiport / track use.
Rate Of Change In Operational Cadence	Month to month and year to year

Guiding Questions: An operational scenario analysis is a missing activity in the original NASA scoping document and is described in this section. It is also noted as a key step early in the Test Design Process (Section 4.1). Analysis questions arose during development of our preferred dose-response test plan which help guide this activity, namely:

- Considering the range of vertiports and temporal aspects of the operational scenarios, at what speeds, altitudes, and operational states will sound from an individual flight event of the specified vehicle type near a given community of interest (near vertiport or cruise zone) rise above the ambient levels in terms of DNL?
- Will there be evening or nighttime operations at any of the potential testing sites?

- Are the enroute operations bundled into corridors? Describe them statistically (backbone and statistical dispersion) in such a manner as to facilitate modeling for dose evaluation.
- Given the UAM industry's intention to fly over areas less populated and less sensitive to noise, what is the proximity of residential locations to the operations? Are they exposed to sufficient UAM noise to span the desired dose range of DNL and other metrics?
- Will the highway in the sky cadence happen in our dose-response testing timeframe? Will there be overlapping time histories in the community and noise monitoring locations?
- For people living under enroute corridors, what kind of operational tempo is needed for the operations to behave as cylindrical sources rather than point sources (like highways)? Are these levels of operations expected at any of the potential vertiport test sites?

Activities: Each of the recommended activities is built upon the prior element. For example, the first step is to identify the vertiport locations within the identified future dose-response testing years. The second step is to identify which vehicles will operate at these locations. Consider for example the Dallas Fort-Worth Texas area. Joby has indicated the possibility of UAM operations in the Dallas Fort-Worth area in the future. For the Joby vehicle at DFW obtain FAA Terminal Area Forecast (TAF) data and develop projections of flight trajectories.

TAF is the official FAA forecast of aviation activity for U.S. airports (FAA, 2025). It contains active airports in the National Plan of Integrated Airport Systems (NPIAS). Forecasts are prepared for major users of the National Airspace System including air carrier, air taxi/commuter, general aviation, and military. It is not clear if UAM operations will be added to the Terminal Area Forecast (TAF) projections in the future.

As an example, examine the existing study where Joby collaborated with NASA to define several DFW area use cases as depicted in Figure 5 (Verma et al, 2022). They subsequently successfully conducted an Air Traffic Control operational simulation with up to 120 operations per hour in the central terminal area, and up to 45 simulated simultaneous eVTOL operations in the DFW Class B airspace (Joby 2023).

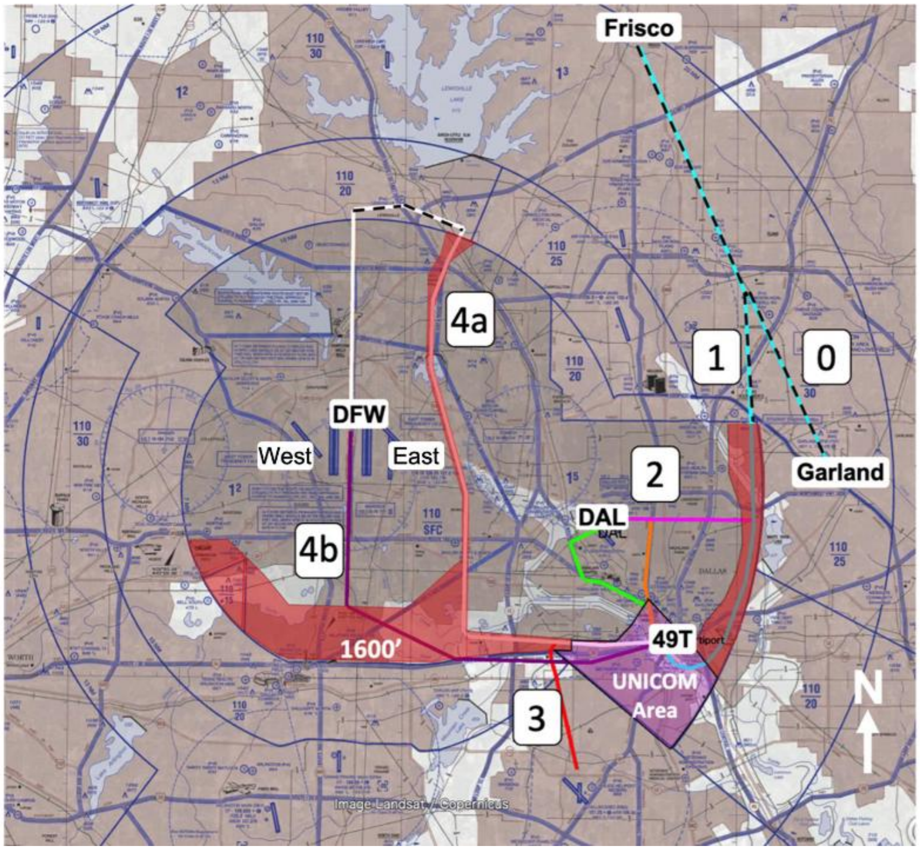

Figure 5. Example Use Cases 0 to 4b for Joby DFW Operations *(Source: Verma, 2022)*

Temporal Analysis: The temporal aspects must be assessed for each of these operations. This includes the operational rates by hour and day and an assessment of what the temporal exposures might be like in the areas of interest. For example, are the operations clustered during typical rush-hour commute periods? Are there nighttime operations? Do things change on weekends? Given local meteorological conditions (winds), is there preferential vertiport or track use either for UAM safety considerations or for deconfliction with other nearby flight traffic? What is the expected change to the operations monthly or seasonally? Consider traffic in both directions along a projected route. What is the prevalence of operations resulting in overlapping acoustic time histories for communities of interest?

Operational Count and Frequency: The operational counts and cadence projections should be catalogued temporally. Since the prevalence of UAM operations is expected to increase over time, and since the UAM dose-response test is projected (albeit with uncertainty) to start in the 2030 timeframe, it is plausible that operations will still be ramping up. In our preferred dose-response test skeleton BRRC suggests both an annual annoyance survey and a longitudinal daily dose-response survey. The rate of change in the projected operations for any given test area will be used to plan the timing of the longitudinal surveys and can provide insights for interpreting the annual dose-response results. If the FAA waits until the UAM operations have reached their annual steady state in a sufficient number of survey locations to achieve "national representativeness", they could be waiting a long time. Conversely, the selection of locations that will have received their steady state number of operations in the near term (e.g., 2030) could be limited and collectively not be considered nationally representative, hence calling into question the validity of the dose-response relationship.

Database Structure: The specific structure of the operational scenario database will need to be determined early. Garnering stakeholder feedback should be considered. The specific data requirements and the way the noise models ingest the data need to be considered.

Coordination for Data Release: NASA and the FAA should evaluate the pros and cons of releasing the scenario database publicly. While dissemination to other researchers would be beneficial and could foster related research (including internationally), it could potentially influence or create bias in the public and impact the future dose-response testing. Consideration should be given to established protocols already employed at airports governing the release of historical and forecast operational data, noise contours and other information.

Data Sources and Considerations: NASA is well suited to conduct or sponsor investigative research[*] to gather and assimilate operational estimates and plausible future operations and growth scenarios considering:

- Are there eVTOL OEM operational and business projections that can be leveraged?
- Have relevant operational scenarios been developed by other NASA groups, universities, and researchers that are looking at the details of UAM airspace integration?
- How well do operational projections agree?
- Can uncertainty in the operational information be quantified?

Potential sources of forecasting information include ICAO / CAEP Modeling and Databases Group which projects future trends.[†] The FAA maintains historical operational flight data from Performance Data Analysis and Reporting System (PDARS)[‡] and NAS Offload Program (NOP).[§]

Opportunities: The Olympics have been identified as an opportunity to conduct measurements. We recommend that the team conducting the operational scenario analysis also evaluate the projected operational patterns, routes, and tempos that might be flown by UAM aircraft at the Olympics and create a database in the standardized operational data format. This information will be important to determine what potential activities are relevant to the technical activities and can provide effective targets of opportunity.

Level of Maturity. Starting with the Uber Elevate white paper (Uber, 2016) and with the business case propositions by various manufacturers, projections of high volume manufacturing and operations (Archer, 2024; eVTOL News, 2023) have been reported. Over the last decade UAM technology has been refined, vehicles have been built and tested, and the regulatory landscape

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[*] NASA funded a demand analysis of the airport shuttle, air taxi and air ambulance markets (Goyal et al., 2018) and updated airport shuttle and taxi markets (Goyal et al., 2021).

[†] https://www.icao.int/environmental-protection/Pages/CAEP-MDG.aspx, accessed 15 July 2025.

[‡]https://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/systemops/perf_analysis/perf_tools

[§§]https://www.faa.gov/sites/faa.gov/files/airports/planning_capacity/Historic-NAS-Data-Release-to-Airports.pdf has evolved, with the UAM industry making tangible progress. But when compared with the well-established civil aviation market, the UAM ecosystem is still in its infancy. As a result, the expected uncertainty associated with projections of future operations will be high, especially initially. As commercial operations are established the FAA will be gathering UAM operational data in the PDARS and NOP and hopefully projections of the UAM operations will be added to the FAA demand driven Terminal Area Forecast (TAF)* database. Basic analysis is needed to identify suitable databases and methods for projecting civil UAM operations at US vertiports.

Technical Risks. The largest risk associated with operational scenario analysis is a potential lack of UAM specific forecasting data and a high level of uncertainty. Since historical data for UAM operations simply does not exist, everything is a projection. There are differing degrees of realism in published operational projections whereby the assumptions and publishing objectives must be closely evaluated. These risks can be mitigated by taking a phased approach. The initial scenarios can be developed for the purpose of guiding the NASA technical challenge activities, with a final scenario update late in the test preparation timeline so that the final operational scenario quantification and identification of test locations will be as accurate as possible for the eventual FAA UAM dose-response test design and execution. Whether the operational scenario analysis forecast data should be disseminated should consider public response and the potential for creating bias in the future UAM dose-response testing.

5.2 Dose-Related Activities

The dose related activities are organized into five primary areas:

- Community Noise Modeling Tools (Section 5.2.1),
- Source Data for Community Noise Modeling Tools (Section 5.2.2),
- Measured UAM Detection, Classification, and Signal Extraction (Section 5.2.3),
- Ambient Tool Development and Validation (Section 5.2.4) and
- Dose Estimation Tool Development, Validation, and Uncertainty Quantification (Section 5.2.5).

5.2.1 Community Noise Modeling Tools

Within the Community Noise Modeling Tools area are four principal activities.

- Identification of Community Noise Modeling Tools (Section 5.2.1.1)
- Assessment, Selection and Preparation of Models (Section 5.2.1.2)
- Model and Modeling Validation and Uncertainty Quantification for Dose Evaluation (Section 5.2.1.3)

The primary goal of this activity is to develop and release a set of validated and documented models suitable for use in the FAA UAM dose-response test.

5.2.1.1 Identification of Community Noise Modeling Tools

The primary outcome of this activity is a short list of models for consideration.

Noise modeling tools need to be commensurate with the eventual FAA UAM dose-response test design to support activities related to test design and planning, and for dose evaluation. As was

* https://www.faa.gov/data_research/aviation/taf

noted earlier, the model itself and the modeling technique (especially related to model capabilities) are of equal importance. The noise models are also needed to support the other NASA activities related to the UAM technical challenges even if they are not used in the final FAA UAM dose-response test.

The tech challenge activities will also have modeling requirements, such as a need to auralize UAM signatures for use in laboratory testing. Given the lack of publicly available UAM acoustic data, configurations might need to be synthesized from first principles for lab testing. The limited empirical UAM acoustic data will need to be adjusted for test purposes (to reflect different altitudes, loudness levels, onset rates) and combined with ambient data (measured or synthesized). These modeling capabilities are not directly required to design or execute the FAA UAM dose-response test so are assumed to be part of the individual testing and are not included in the model development and validation activities.

The future UAM dose-response test will impose requirements for the models and the modeling related to the parameters in Table 5.

Table 5. Model and Modeling Related Parameters

Integrated vs. simulation capabilities	Vertiport vs. enroute zones
Spectral content (directivity/frequency range)	Desired metric outputs
Point / line sources vs. spheres	Auralize and synthesize listenable sounds
Modes of flight / operational states	Meteorological effects
Complexity of vehicle designs	Environmental effects (terrain / shielding)
Single vs. multiple event operations	Receptor locations (ground, 4ft, high rise)
Scenario and integrated dose modeling	Input data (ops/noise sources/meteo/environ)

Many steps in the noise model development are already well underway at NASA including tools for source modeling from first principles which can be applied to different UAM configurations (such as NASA has applied to the RVLT reference vehicles). Identification and a description of potential noise tools is provided in Section 2.4.2.1. It would be beneficial to also consider other modeling tools in use internationally. A literature review might be warranted for this task.

The community noise modeling tools need to be identified early in the project with a milestone identifying and acquiring the specific noise modeling tools for consideration. The candidate modeling list will flow into the Assessment, Selection and Preparation of Models activity.

Level of Maturity. The maturity of each model needs to be identified as part of this task considering model longevity, technical validation status, and whether it is being actively developed and maintained.

Technical Risks. The models need to be accessible and usable by NASA and others. Consideration should be given to the ability to make modeling changes or incorporated corrections to the model output. Input data for the models, specifically UAM noise characteristics, are scarce, and methods to acquire or develop such data should be identified as part of the activity.

5.2.1.2 Assessment, Selection and Preparation of Models

The outcome of this subtask is a set of improved (but unvalidated) models ready for validation. The activities include:

- Comparing the desired modeling features and fidelity with the tool capabilities,
- Down selecting the tools to support dose evaluation methodology, and
- Preparing and refining the models incorporating necessary features and fidelity enhancements.

The models need to support a) dose response test planning (specifically in support of decision making regarding recruitment stratification) and b) noise prediction in the communities for the purposes of dose evaluation.

Since our preferred approach for the FAA dose-response test is to employ a dual zone strategy, the assessment may consider both zones separately*. Each zone could have considerably different source operating states, environmental conditions, and ambient characteristics, which can interplay with the models and affect the down selection outcome. Because of the different nature of the UAM operations in the zones, a different model might be selected for each zone for further development.

The expectation is that the projected operational scenarios (data deliverable from the Operational Scenario Analysis described in Section 5.1) will be ready for use in the models.

Analysis in Dual Zones

Initially the analysis can be separated into vertiport and enroute zones. The test skeleton notes parameters necessary for capturing the effect of the operational scenarios for recruitment stratification. The goal of this activity is to apply the models to the operational scenarios and evaluate the modeling fidelity in each zone. The analysis will involve predicting metrics for aggregated operations on an annual and daily basis for these parameters. Based on the model capability and performance they will be down selected for continued improvement and input data preparation. The result could be two models for the two zones.

This task involves evaluating the models using a few realistic scenarios to demonstrate that they can provide the necessary output metrics for the projected scenarios and the environmental conditions at potential future dose-response test sites.

Is one model suitable for both zones and will two models need to be carried forward? For example, at a selected vertiport location, compute the single event metrics for a variety of the prevalent operations identified in the operational scenario analysis in both zones. Then assess modeling performance and capabilities including:

- Does it matter which specific vehicle types are being modeled?

* The decision to use the dual zone approach is made later in Y2Q3, in the model and modeling validation and UQ for dose evaluation task after the tools have been applied to a sample of the projected operational scenarios.

- What do the noise contours look like (e.g., are they closed contours of specific levels near the vertiport zones but essentially parallel, decreasing with distance from the corridors in the enroute zones?)
- Can one model capture this fidelity in both zones? It could be that several models are adequate for the cruise zones, but a more sophisticated tool (and associated acoustic input data) is needed for the dynamic operations in and near the vertiport zone.
- Can simplifications be made in the single event model inputs that preserve the output noise? For example, can a climb, transition, and cruise segment be modeled by only three different source datasets (spheres/NPDs), or is higher fidelity required?
- What outputs (e.g., spectral time histories) can the models support for evaluation of more sophisticated metrics (post processed if necessary) such as ambient related metrics?
- In evaluating the environmental conditions (terrain, urban factors, meteorology), what modeling features need to be included in the noise predictions?
- Are correction techniques applicable (e.g., compute effects separately and apply metric deltas to points of interest) or can new features be applied within the selected models?

Overall Zone: Single Model / Blended Model

With the noise contours (of various metrics) in hand and the dual zone test design progression (specifically the recruitment sampling planning) one can assess if two separate models can be used for the two zones, or if a blended approach needs to be made. Techniques that have been used in the past for blending modeling capabilities are described in Section 3.1. If a blended modeling approach needs to be used for combining the two models to project the noise everywhere (not just in the two zones), it should be developed, tested, and prepared for validation in subsequent activities.

The list of models under consideration flows in from the Identification of Community Noise Modeling Tools activity. Other inputs include the operational scenario analysis database, the ambient database and information about the statistical structure of ambient noise at home. A decision will be made as to which models warrant further investigation and development for test design and dose evaluation process. A significant outcome of this activity is a set of models ready for validation.

Level of Maturity. The maturity of the models and input data will improve because of model preparation and improvements associated with this activity.

Technical Risks. One big risk is identifying the wrong model for preparation for the FAA UAM dose-response task and having it rejected at the end and having to compute the doses with a different model. Another risk is that the desired model feature improvements cannot be prepared in time, due to the lack of control over the model development cycles and competing regulatory demands. These risks can be mitigated via communication with the FAA and other stakeholders and via coordination with the model developers.

Another major risk is the lack of availability and inability to obtain suitable input acoustic data for the UAM vehicles of interest. For model assessment, surrogate data could be used. In the validation tasks, available vehicles (for which suitable input data is available) can be used, however subsequent validation updates will need to occur for the vehicles of interest in the dose evaluation (after the source data activity obtains suitable validation data).

A related risk is the advent of unanticipated operational conditions or scenarios where the models are not performing well either due to lack of modeling capability (e.g., consideration of wind effects) or due to lack of input data (e.g., a transition mode with unique acoustic characteristics for which source noise data does not exist).

5.2.1.3 Model and Modeling Validation and Uncertainty Quantification for Dose Evaluation

The outcome of this subtask is an accessible set of validated models with quantified uncertainties suitable for evaluation of single event, daily and annual cumulative metrics for various operational scenarios, and a document describing modeling best practices and guidelines.

This activity will utilize the models developed in the previous activity "Assessment, selection and preparation of models" and apply them to the operational data prepared in the operational scenario analysis activity (Section 5.1). A key decision under this activity is whether the dual zone testing approach will be recommended for the future FAA UAM dose-response test. This decision will include the results of the tool evaluation for realistic scenarios and will also depend on the sampling activity findings (Section 6.3.1).

The dose metrics of interest, single, cumulative noise metric (DNL for an annual average day) and the other modeling metrics (such as average busy day) need to be analyzed. Section 5.3.1 describes cumulative dose modeling concepts and Section 5.3.3 includes metric related activities. This activity is where the selected tools' ability to capture modeling concepts are evaluated for handling multiple operations in realistic environments. The approach is a buildup of complexity from single event to daily to annual (e.g., average) dose. The modeling assessment is coupled with the response-related sampling activities in that those will help define what kind of stratification the tools need to support for the test planning stage. Similarly the Dose Estimation Tool Development, Validation, and Uncertainty Quantification (Section 5.2.5) will inform what the models need to support regarding projections of the dose at the participant locations during the survey periods. An important element of the analysis process will be to evaluate model uncertainty.

Model testing using several operational scenarios may take the form of sensitivity tests. This activity needs to evaluate the level of modeling operational input simplifications that can be made while preserving the output contour levels and shapes (e.g., bundling the operations and modeling them as a backbone and distribution rather than individually; or by grouping similar departure and arrival profiles). This will provide an understanding of the modeling simplifications that can be conducted while yielding the same or similar answers, and an evaluation of how they vary across the different tools. A set of modeling best practices and guidelines should be developed and reviewed by stakeholders* and released.

An opportunity for a real world test of the models is the Los Angeles Olympics in Y3Q2 and will require several activities including: assessing noise levels based on operational projections,

* The review and release activity should involve the UNWG, coordination entities, and standards groups noted in the scoping document.

assembling suitable model acoustic data inputs for evaluation of noise contours and metrics across the region and at specific points of interest for planning purposes, and assessing background noise characteristics in areas of interest for evaluation of ambient based metrics. Plans can be developed in conjunction with testing new measurement technologies (e.g., signal extraction techniques) to obtain data to be used to validate the model(s) and to validate the modeling techniques (e.g., source data substitution, bundled operations, simplified profiles etc.).

This activity is designed to test and validate the noise models for noise computation and to quantify the uncertainty for: single event dose, cumulative daily dose and cumulative annual dose. This activity includes a key decision (made in conjunction with response related activities) about whether the dual zone testing approach will be carried forward. The final output is validated modeling tools with quantified uncertainties that can be used in the FAA UAM dose response test.

Level of Maturity. At this point in the technical challenge the tools should be maturing and applicable to realistic scenarios for test design and dose evaluation purposes.

Technical Risks. A blended model, rather than a single model applicable across everywhere the UAM noise will reach, could introduce risks to the dose evaluation. Although the dose evaluation will be at specific residences, one needs to create contours across the whole test area for use in test design and recruitment activities. These will need to be smooth enough for sampling.

5.2.2 Source Data for Community Noise Modeling Tools

The community noise modeling tools described in Section 5.2.1 all require source noise data of some form. The primary outcome of this activity is validated and (to the degree possible) released acoustic source data for the noise models and documented procedures and best practices for developing the noise model acoustic data.

Activities in this area include identification of source data gaps needed for the modeling, development of procedures to obtain empirically based source data, and quantification of uncertainty for the identified source data estimation methods. The activities need support and align with the Community Noise Modeling Tools (Section 5.2.1).

Often the acoustic data used in models, in the form of NPDs or sound hemispheres, are obtained from dedicated flight test measurements under ideal conditions, which is the preferred approach. However, other mechanisms for developing community noise model input data are possible and have been used. These techniques could include:

- Applying hybrid modeling and empirical methods
- Estimating noise source levels and characteristics based on
    - FAR-36 certification data
    - Limited measurements of opportunity
- Substituting existing aircraft data for the vehicle of interest
    - Perhaps with an operational scaling factor applied to the operational counts
- First principles modeling

5.2.2.1 Assess Data Suitability, Develop Source Procedures and Quantify Uncertainty

The first outcome of this activity is draft procedures and best practices for developing acoustic model source data. The second outcome is a data development plan for the UAM vehicles of interest that leverages the procedures and best practices. This plan will then be executed as separate source data development activity.

The first step is to evaluate what vehicle acoustic source data is needed for the models*, and what data is available. This should include assessment of the 3D spectral noise spheres and NPD data for the operating states of interest. Identification of the vehicle types of interest and relevant operational modes will be based on the data from the Operational Scenario Analysis activity. The Model and Modeling Validation and Uncertainty Quantification for Dose Evaluation activity (Section 5.2.1.3), will identify appropriate noise modeling simplifications that can be applied in the analysis.

The goal is to identify for each vehicle of interest and operating state if the data already exists, and if not, to develop a plan for filling the data gaps via estimation or measurement. Another important aspect of this activity is to assess the source data uncertainty for use in the dose evaluation.

There are at least three avenues identified below for source data development. They include using FAR-36 measurement data, measurements of opportunity, and hybrid prediction / modeling methods. It is possible that a combination of all three (and possibly additional techniques) will be needed to develop the full set of acoustic model input data for each vehicle.

Leveraging FAR-36 Empirical Data

All commercial UAM aircraft models will need to be certified using the procedures outlined in FAR-36 and ICAO Annex 16, Volume 1. BRRC assumes such data will be made public for certified UAM vehicles as it has for other commercial aircraft†. Procedures have been developed for rotorcraft using certification right/center/left directivity approximations and a single spectrum to generate noise sphere data for use in simulation noise models (Page, 2003). 14 CFR Part 36 data can also be used in integrated models for generation of NPD data for AEDT (Boeker, 2019). A process has also been developed and applied to conventional rotorcraft data for AAM spheres for DoD NEPA modeling based on surrogated directivity and calibrated adjustments to the noise spheres (Page, 2012). There could be limitations as to the breadth of UAM operational conditions that can be represented this way but pending the findings from the tool development task these concepts might be sufficient. Such limitations will be reflected in the uncertainty quantification.

Leveraging Measurements of Opportunity

The NASA scoping document notes potential measurements of opportunity including UAM operations in the UAE and the Los Angeles Olympics. The plans will need to be examined in more detail to develop a credible measurement test plan. If ambient conditions do not have sufficient SNR over the desired duration of time history to facilitate classical source measurement

* As part of the Assessment, Selection and Preparation of Models activity, a decision will be made as to which modeling tools warrant further investigation and development (B1.2).
† https://www.easa.europa.eu/en/domains/environment/easa-certification-noise-levels

techniques (e.g. linear arrays, snapshot arrays, left/center/right microphones for NPD development) measurements from the point of closest approach (e.g., LAmax and OASPLmax) and the recorded spectra can possibly be used to 'scale' other available data.

The Olympics will provide opportunity for testing the technology developed under the Field Testing and Demonstration activity and if successful, the empirical data can be leveraged for source characterization too. Other data acquisition opportunities should be considered, such as coordination with OEMs (through joint testing or OEM data sharing), leveraging certification measurements with the FAA and UAM operations in other places.

Hybrid Prediction Methods

The hybrid prediction methods activity is focused on creative combinations of methods and data. Functionally spheres can be distilled into NPDs, and with some assumptions NPDs can be made into spheres (Downing et al., 2020). The Hybrid prediction Methods area should assess the feasibility of using first principles models for prediction of source characteristics that are calibrated using some form of measurement data. For example, there is active development of a hybrid method FRAME, (Greenwood, 2012) for conventional rotorcraft that "tuned" CHARM based on a limited set of empirical data, facilitating the prediction of source characteristics in all directions and for other operating conditions (Wachspress, 2024). The output noise spheres can be used with simulation noise modeling tools which in turn can be used to develop NPD data for integrated models. This kind of modeling approach can also be applied to UAM aircraft.

Each of the development procedures and best practices should be documented for wider dissemination and review by the UAM community. The acoustic datasets for the noise models should be updated with validated data and tested procedures towards the end of the activity.

Level of Maturity. Many of the strategies for transforming, scaling and applying empirical data in one form to another (spheres→NPDs and NPDs→ spheres) have been used in limited fashion. Measurement procedures for acquiring source data are well established, but in idealized environments.

Risks. The most significant risk is a lack of suitable data resulting in data development methods with higher uncertainty levels. This could in turn result in larger levels of dose uncertainty.

5.2.2.2 Acquire Source Data (NPDs and/or Hemispheres)

This activity executes the data development plan developed under Section 5.2.2.1. The deliverable is the model acoustic source data (Y3Q4) in the form of NPDs, hemispheres or as appropriate for the models. A measurement of opportunity (Olympics) is noted in the schedule to acquire data for model input development and/or validation.

Level of Maturity. This activity relies on new technology developed under the Signal Detection activity so will be inherently risky.

Risks. The primary risk is encountering difficulty in extracting useful UAM noise from background data obtained from measurements of opportunity.

5.2.3 Measured UAM Detection, Classification, and Signal Extraction

This activity addresses the question, "How do you detect and classify UAM noise in the presence of high ambient environments and confounding noise sources, and how do you extract the UAM signal for analysis?" Signal processing methods are needed to identify UAM events, reject non-UAM sounds (including potentially other aviation noise sources such as fixed-wing aircraft and helicopters), identify the relevant noise exposure, and calculate metrics amongst the ambient sounds. This topic has heightened priority due to 1) the likelihood of UAM flight paths in dense urban environments and 2) the relatively low signal-to-noise ratios, especially for enroute zones.

The NASA scoping document identifies signal processing methods that will need to be developed that address the following:

- how to measure signals in a high ambient sound environment,
- how the data of interest affects signal processing requirements,
- the use of multichannel systems and processing for time-of-arrival or beamforming-based algorithms, and
- the value of using ADS-B for tracking.

These items are a good first-pass at the required signal processing tools needed for UAM measurements, and BRRC would like to address additional considerations in the development of signal processing.

1. ***What is an acceptable signal-to-noise ratio for UAM measurements?***

   By design, manufacturers are developing UAMs to be especially quiet relative to other airborne vehicles (Uber Elevate, 2016). However, from a measurement perspective this increases the challenge of capturing quality recordings. It is probable that UAM overflight noise will not be the dominant noise source during measurements in such areas. BRRC encourages NASA to develop criteria that helps to balance expected signal quality with other siting requirements such as proximity to the flight track and operational tempo.

2. ***What methodologies can be implemented to improve a UAM measurement's signal-to-noise ratio?***

   Ambient (or interfering) noise sources are likely to be at a relatively high level compared to the UAM signal level. Where possible, BRRC recommends that sites be located to minimize ambient noise. However, BRRC recognizes that many sites may result in poor measurement quality due to confounding acoustic factors. BRRC recommends that NASA develop and test technologies to improve the SNR for UAM measurements. NASA mentioned multichannel systems and beamforming in the scoping document, and BRRC agrees that beamforming using phased-array data can effectively improve the UAM SNR so long as the UAM location and track are known (see question on non-acoustic methods to track UAMs).

   In addition to phased-array methods, any multichannel approach that isolates either the noise or the UAM signal can be used to enhance the SNR. For example, if a loud, persistent, factory machine is near the measurement location, a dedicated microphone could be placed very near to the machine noise. When a UAM passes, the measurement microphone would record the UAM signal as well as noise from the factory machine. In post-processing, the analyst calculates the cross-spectrum between the measurement (signal plus noise) microphone and the factory noise (noise only) microphone. By subtracting the cross-spectrum of the two measurements from the autospectrum of the measurement channel, this two-microphone approach can isolate and remove the factory noise from the measurement channel.

For single-channel measurements and patterned noise sources such as horns, sirens, and jake brakes, AI could be developed and employed to identify, mark, and remove the noise contributions from the pressure time history.

3. ***What is the role of acoustic methods to detect, identify, and track UAM sources?***

   As an acoustic study, it seems the first choice for detecting, identifying, and tracking UAM noise should be using acoustic methods. BRRC encourages NASA to explore what role acoustic techniques can play in these efforts. For example, certain tones in UAM noise could indicate a certain aircraft and flight configuration. The same principles could also be used to identify other UAM and non-UAM aircraft, such as helicopters and general aviation aircraft. If the UAM is sufficiently loud, the noise levels could be used to trigger the start and stop of an acoustic measurement. However, the expectation is that UAM noise will be broadband and low-level in many flight configurations, making detection, classification, and tracking more difficult for a system based solely on acoustics.

4. ***What is the role of non-acoustic methods to detect, identify, and track UAM sources?***

   NASA mentioned the need to investigate ADS-B for tracking UAMs. BRRC agrees that ADS-B should be investigated and would like to clarify that ADS-B is potentially useful for detection, classification, localization, and tracking (DCLT). This utility extends not only to UAMs but also to aircraft and rotorcraft with ADS-B devices. To the extent that UAMs and other aircraft transmit ADS-B messages, the ADS-B data would include identifying information, providing information on other nearby airborne vehicles, and at least a rough estimate on the UAM's location and track. The effectiveness of ADS-B for localization and tracking is unclear and depends on the required resolution. For example, if ADS-B trajectories are used as inputs for phased- array processing, the trajectory may be delayed or translated in space, which could produce severely degraded beamforming results.

   NASA should also consider known UAS flight tracks when processing measurements. UAS manufacturers have been developing UAS systems in unmanned capacities using pre-programmed routes. The aircraft are therefore capable of strict adherence to preprogrammed flights such that detailed tracking may be unnecessary if the flight track and the time of closest approach (TOA) are known.

   If a high-fidelity trajectory is required, other non-acoustic techniques should also be explored. For example, video cameras are frequently used in conjunction with fixed-wing aircraft phased-array measurements (see Figure 6). Artificial intelligence (AI) based object detection methods could be employed on the calibrated camera data (in real-time or in post processing) to pour through, identify, and provide an optic-based track that could be mapped to the bearing required for the phased array processing.

Figure 6. Optical Tracking Example. *(Source: Blais et al., 2013)*

Other public data such as air traffic frequencies and published regular flight times should also be considered when determining more general times when the aircraft will be in the air.

BRRC also encourages NASA to monitor advances in small, air-search radar systems (both the technology and use policy), as this emerging technology is being developed to monitor for sUAS and could be useful for this application.

5. *What are the criteria for determining if a measurement system needs to be manned?*

BRRC encourages NASA to consider any required manned measurement systems. An on-site trained operator can monitor ambient conditions, detect and classify UAS passes, verify hardware measurement status and health, and document event quality. However, manned systems are not always feasible when multiple systems are deployed or if measurements extend beyond a few days of monitoring. For example, it would be impractical to have an on-site operator for each sound level meter if twenty such meters were deployed during the Los Angeles Olympics for nearly a month. However, when choosing unaccompanied measurement systems, BRRC encourages NASA to select robust, durable, tamper-resistant systems and consider the physical security risks of unattended monitoring.

6. *How does the UAM operational tempo affect measurement and analysis methodologies?*

UAM operational tempo will likely influence measurement campaign duration, whether or not to deploy manned measurement systems, and the amount of resources to devote to more sophisticated measurement and analysis techniques. Low operating tempos (≤1 event per hour) would result in a handful of events per day. When analyzing the results, more time could be devoted to each flyover to identify and extract each event. Conversely, high-tempo UAM flights would make programmatic methods for detection and measurements more desirable. When analyzing the results, programmatic methods for performing quality assurance and metric calculations would also be ideal rather than manual extractions.

With these open considerations, BRRC has subdivided the Measured UAM Detection, Classification, and Signal Extraction activity into four components: methods development, desktop synthesis and testing, field testing and demonstration, and data analysis.

5.2.3.1 Methods Development

In this task, NASA will develop methods that will be used in numerical simulations, for field test measurements, and in post-processing to analyze the results. NASA will explore and compile a ranked list of methods they have determined to be viable and most effective for eVTOL applications. These methods will fall into three categories: detection methods, classification methods, and signal extraction methods. Section 2.4.3.3 explores multiple methodologies for detecting, classifying, and extracting UAM signals in the presence of high ambient sound levels.

Detection methods include acoustic and non-acoustic techniques to detect the presence of a UAM in real-world scenarios. This could include level-based band passed acoustic triggering, tonal frequency detections, ADS-B data of a UAM in the vicinity, or optical detection.

Classification methods are those that can identify the detected object as a UAM or non-UAM, reject ambient and other noise sources, and provide other identifying information such as the eVTOL model. For example, ADS-B usually includes identifying information on the corresponding aircraft. Tonal analysis of a signal can characterize and reject a passing propeller general aviation aircraft. A video feed fed into an image recognition software can identify various aircraft models.

Signal extraction is a task for identifying and removing any undesired ambient noises from a signal. These methods vary in their implementation. For example, signal extraction could include phased array data input into a beamforming algorithm to reject signal from locations other than where the expected UAM is located. For phased array development, a suitable phased array geometry should also be investigated. Phased array measurements may be coupled with localization and tracking methods to aid in estimating the trajectory of the UAM. Other signal extraction techniques could include estimating the ambient noise level so that only levels above a certain threshold are considered. This task could also include programmatic methods for automatically cropping the signal-portion of a flyover event so that hundreds or thousands of recordings could be processed for metric calculations.

Once methods are selected and ranked, the most likely candidate methods will be identified for development for use with both numerical and field test data. If the selected methods require additional signal processing tools, these will be developed in tandem with the methods. Hardware requirements for field testing will be identified for the selected methods.

The methods development task involves identifying and developing the detection, classification, and signal extraction methodologies that are most likely to be effective. An early milestone is having the methods developed numerically in Y1Q4. These will then be utilized in desktop synthesis and testing, relying on the ambient database signals described in Section 5.2.4.1. This activity will enable a down select decision in Y2Q3 about which methods to pursue. Two field tests are planned in Y2Q4 which could utilize surrogate aircraft in lieu of UAM operations. A measurement of opportunity at the Olympics will demonstrate the effectiveness of the newly developed noise monitoring technologies.

Level of Maturity. Development of the methods is the heart of this activity, and the optimal technique could differ for the vertiport vs. enroute zones. In the case of the ADS-B method, maturity is likely higher if the X-59 GRS ADS-B technology can be leveraged, though it is unclear how effective ADS-B data is for real-time tracking and whether the resolution is sufficient to use when applying to phased-array data, for example. The maturity of acoustic triggering, tonal frequency detection, and acoustic phased-array technology are well established, but the successful application of them to UAS noise is currently unproven. Optical detection methods are available but will require sufficient effort to mature and field the technologies. Phased array technology has been in practice for a while, but the application is unproven in urban environments with competing aviation operations.

Risks. The technical risks should be evaluated in this task for each of the methodologies. The risks should be used to guide the decision-making process when prioritizing methodologies for follow-on tasks. The overarching technical risks guiding this activity are:

- A UAM will not be detected during a transiting event,
- A (UAM) signal will be detected but improperly classified,
- A UAM signal will be detected and correctly classified, but the recording quality will be poor. This could result from incorrect start/end recording times, low signal-to-noise ratio levels from general ambient levels, or confounding noise sources either on the ground or airborne.

The complication of measuring UAM noise in situ is a significant risk for the FAA UAM dose-response test. UAM acoustic data is needed for multiple purposes including model and modeling validation, development of acoustic input data for the noise models and ultimately for dose evaluation. Concurrent technology development for several strategies will help reduce risk.

5.2.3.2 Desktop Synthesis and Testing

This activity goal is to create a testbed framework for applying and testing the methods developed in Section 5.2.3.1. This task will acquire or model UAM signals injected in ambient noise and quantify the effectiveness and uncertainty of each method to detect, classify, and calculate the UAM noise metrics utilized in the dose evaluation tool development (Section 5.2.5).

First, the UAM signals for testing need to be acquired and/or synthesized. The signals should span a variety of expected manufacturer signals under different flight profiles, trim states, and configurations. These signals should ideally have minimal or no ambient noise, so additional efforts may be necessary to minimize noise contributions for selected signal recordings.

Once a UAM signal database has been generated, signals can then be injected into realistic ambient conditions. The ambient dataset use for this task will be generated as part of a separate activity (Section 5.2.4.1) and mixed with the UAM signal datasets to develop a database of realistic case studies. As necessary, the available signal data can be 'morphed' to approximate trim states or configurations where there is insufficient data.

Once numerical case studies have been established, the selected detection, classification, and signal extraction methods previously developed will be applied to quantify the success rates, failure rates, and uncertainty of each method leveraging key acoustic metrics to identify signal extraction uncertainty rates. Quantified metrics on the probability of detection, false-alarm rates, and uncertainty for the detection and classification methods and quantified metrics on the uncertainty of the extracted signal metrics will be computed. As appropriate, refinements to the developed methodologies will be developed and applied.

Numerical data will be applied to the developed methods using desktop synthesis and testing. An early milestone is a database of UAM signals that spans multiple flight profiles, trim states and configurations, and UAM models to encompass the various acoustic measurements in the future FAA UAM dose-response test. The success rates, failure rates and uncertainty of the methods will allow down selection of the methods for further testing.

Level of Maturity. The methods developed will be at a sufficient maturity level for application to simulation datasets. Test signals will be acquired from previous UAM measurements or from modeling efforts. The maturity of modeling efforts to generate satisfactory UAM signals will be evaluated as part of this task. The ability of UAM models to simulate UAM signals at various trim states and configurations for realistic scenarios should be investigated. An ambient signals database will be developed as part of a separate activity (Section 5.2.4.1).

Risks. UAM signal acquisition over a sufficiently large database of diverse UAM signals presents the largest risk but can be mitigated via synthesis from modeling tools. This could result in higher uncertainties and might necessitate significant updates to the framework when empirical data becomes available.

5.2.3.3 Field Testing and Demonstration

Once the methods are developed and tested in numerical case studies, three field measurement tests will be designed and conducted to acquire data that will be used to evaluate success, failure, and uncertainty rates of the methodologies as applied to measured data. Field test preparations are necessary for each of the testing components, including scoping the test to only collect pertinent data, acquiring necessary hardware for collecting measurement data, and conducting the field tests.

The three field measurements studies include detection and classification field testing, trajectory estimation testing, and testing for UAM measurements of opportunity. In the detection and classification field test, a suitable location will be determined with characteristics like the future UAM operations. The purpose of this first test is to collect data pertinent to the chosen detection and classification methods. For acoustic detection methods this could include acoustic triggering off rotorcraft or fixed-wing aircraft while rejecting ground-based noise sources. For non-acoustic detection methods such as ADS-B detection, a field test could be collecting ADS-B data in the vicinity of a helipad. Classification methods could involve acoustic signature recognition or ADS-B identifying information. This test could be designed to not require UAM measurements to simplify acquisition strategies.

If, during the methods development phase, signal extraction does not rely on trajectory estimation, a decision could be made whether to forego the trajectory estimation testing. The decision on the measurement of opportunity test period may affect the tasking schedule for related task elements, and the schedule may need to be adjusted as necessary. The trajectory tests can be designed in a similar vein. Trajectory estimation testing should collect data pertinent to the chosen trajectory methodology and need not necessarily be that of UAM data. For example, collecting trajectory data of a chosen rotorcraft over an established duration could be an effective UAM substitute. Both detection/classification and trajectory estimation field testing should include secondary methodologies (e.g. manned data collection sites, actual trajectory data, etc.) for validation purposes.

The final field test is the collection of UAM measurements of opportunity. For example, the Los Angeles 2028 Summer Olympics will be an event where UAM manufacturers are expected to demonstrate flights in the urban environment. These *in-situ* measurements will provide the opportunity to collect operational data[*], acoustic measurements as well as the ancillary data needed to successfully improve the signal-to-noise ratio of the signal. This may include phased-array measurements coupled with the detection and trajectory methodologies needed to record and track the UAM as it passes a data collection site.

These three field tests will require planning and proper scoping to capture the pertinent data that will be used to qualify and validate the methodology. As part of the planning procedures, hardware will be identified and acquired.

There are three tests in this activity designed to acquire data that will be used to evaluate the developed methodologies: detection field test, trajectory estimation field tests and UAM measurement of opportunity test. The outcome is demonstrated methods.

Level of Maturity. The testing activities rely on the maturity of the selected and developed methods from the precursor tasks.

Technical Risks. The significant technical risk associated with this task involves the final test measurement and the maturity, operational tempo, and ability of NASA to deploy measurement systems for the Olympics measurement of opportunity with UAM flights in urban environments. UAM aircraft are in active development and their status for passenger travel, flight demonstrations, and realization of operations at the Olympics is uncertain.

5.2.3.4 Data Analysis

This activity's objective is to quantify the probability of detection and false alarm rate of the detection methods. The data collected under the field test and demonstration task (Section 5.2.3.3) will be used as inputs to evaluate the detection, classification, and signal extraction

[*] Trajectory data will be needed. Advance coordination with OEMs is suggested to understand planned trajectories and will aid in the estimation of actual trajectories in the field. OEMs may be willing to provide as-flown trajectories. Stochastic trajectory variation can be assessed from such data for modeling purposes.

methodologies. They will quantify the success rates of classification to validation metrics. They will quantify the tracking method insofar as needed to support additional methods such as signal extraction (e.g., providing input to beamforming steering vectors). They will quantify the uncertainty of the signal extraction method leveraging the measured data against the simulated uncertainty quantification performed in Section 5.2.3.2.

The final deliverable is a report that includes the following items based on the application of the methods to measurement data:

(1) Documented probabilities of detection and false alarm rates for the detection method,
(2) Documented uncertainty values in the classification method,
(3) Documented signal extraction uncertainty values,
(4) Recommended methods for each measurement zone,
(5) Recommended protocols for each method,
(6) Lessons learned from the Olympics measurements of opportunity.

Coordination with stakeholders and standards organizations should be considered for publication of the recommended protocols. The testing results and lessons learned should also be disseminated so they can be leveraged by practitioners conducting the future FAA UAM dose-response testing.

Level of Maturity. The level of maturity follows from the development and testing from prior tasks.

Technical Risks. The primary technical risk for this task is insufficient data collection for methods analysis. In this case, there will be heavier reliance on simulated results when establishing recommendations.

5.2.4 Ambient Tool Development and Validation

In urban environments, UAM noise may be completely or partially masked by the ambient noise. The ambient noise environment will affect both the dose measurements and the human responses to UAM noise. The following sections describe the recommended research activities to characterize the ambient noise environment.

5.2.4.1 Identify Ambient Characterization Needs

The first research activity is to identify the specific needs for ambient noise characterization. For test planning, the ambient noise environment may influence the zonal approach selected for the preferred test design. For dose-related activities, knowledge of the ambient noise environment is needed to site acoustic measurement systems in low-noise environments and to extract UAM noise signals from measurements that include ambient noise. For response-related activities, knowledge of the ambient noise environment will help interpret the effects of ambient noise on human responses, especially when the UAM signal is completely or partially masked by ambient noise. These activities require different levels of fidelity for ambient noise characterization. For example, site selection and response-related activities may require predictions of the one-third octave ambient sound levels, whereas extracting a UAM signal from the ambient noise will require recordings of ambient noise waveforms. NASA should specifically identify the ambient noise characterization needs to align the remaining research efforts.

Level of Maturity. Prior studies by Rizzi et al. (2025) and Thai et al. (2025) have explored the effect of ambient noise on annoyance to UAM as well as methods for predicting the ambient noise. The maturity of the models to provide all the necessary ambient factors for effective ambient based UAM metric evaluation has not yet been determined.

Risks. Prior dose-response tests for transportation noise sources have generally not considered masking by ambient noise. The UAM community response tests will require novel research to incorporate ambient noise into the dose-response testing approach.

5.2.4.2 Ambient Noise Model Development

Existing models of ambient sound levels, such as BRRC's AMBIENT model, can predict one-third octave ambient sound levels in communities across the United States. These predictions have been applied to assess discounted annoyance due to masking of UAM signals by ambient noise (Rizzi et al., 2025; Thai et al., 2025). These predictions are also useful for selecting acoustic measurement sites in low-noise environments. Based on the ambient noise characterization needs identified above, NASA should evaluate existing models of ambient sound levels to determine whether they are suitable to support UAM community response testing. This assessment may include the models' accuracy, available metrics, spatial resolution, and temporal resolution. If necessary, NASA should invest in further development of the selected ambient noise model to support the UAM community response tests.

Level of Maturity. The National Park Service and BRRC have produced existing ambient noise models. BRRC's AMBIENT model can predict hourly one-third octave metrics at 30-meter resolution across the United States.

Risks. Existing ambient noise models are primarily empirical and depend on long-term ambient noise measurements for accurate predictions. Additional ambient noise measurements may be required in communities of interest to ensure sufficient model accuracy.

5.2.4.3 Ambient Noise Measurement Approach

Depending on the needs identified above, ambient noise measurements may be required during UAM community response tests to quantify the dose relative to ambient and to interpret responses relative to ambient. An ambient noise measurement approach should be developed that provides the ambient noise data required to evaluate metrics, analyze the doses and responses. Ambient noise measurements will likely use the same instrumentation already deployed to detect and quantify UAM noise signals, but ambient measurements will occur at times when UAM aircraft are not operating nearby. The duration and tempo at which ambient measurements need to occur and the metrics to record should be determined. For example, this activity should evaluate which measurement approach is more useful: logging one-third octave spectra every second throughout the day, or recording a short ambient waveform at the start of every hour? The approach will need to balance the level of fidelity required for the community response tests, the temporal variability of the ambient environment, the power consumption of the instrumentation, and the data storage requirements in developing the ambient noise measurement approach.

The Olympics serve as a measurement opportunity for testing the model and methods developed under this activity. Ambient data measured during the Olympic test can be used to validate the ambient noise model. Identified ambient procedures and requirements for monitoring can be used and assessed. Measurements of noise during concurrent dose-response surveying at the Olympics can serve as a test bed for evaluation of ambient-aware metrics.

An outcome of this activity is a recommended tested and validated practice for ambient data recording for the purposes of metric evaluation and dose estimation.

Level of Maturity. Numerous commercial sound level meters are available for long-term ambient noise measurements with one-second logging and ambient waveform recording capabilities.

Risks. Ambient noise measurements will quantify the ambient noise environment at the specific locations and times of the measurements. Extending these measurements to other locations, such as survey participants' residences, may require additional research to fuse the measurements with existing ambient noise models.

5.2.4.4 Incorporate Ambient Noise into the Dose-Response Tests

Since ambient noise will affect both the dose measurements and human responses to UAM noise, ambient noise should be incorporated into the UAM community response tests in both the dose-related and response-related activities. For dose-related activities, NASA should identify appropriate acoustic metrics that represent UAM noise relative to ambient noise. These metrics may be alternative or supplemental metrics to DNL. One metric that NASA has already developed is the discounted annoyance due to complete or partial masking of a signal by ambient noise (Rizzi et al., 2025). NASA should continue developing this metric for large-scale UAM signals based on laboratory response tests. The discounted annoyance metric requires one-third octaves, which existing ambient noise models can predict. Any further metric development should ensure that ambient noise models and measurements can provide the level of fidelity required to compute the metric.

Level of Maturity. NASA has already developed a discounted annoyance metric due to complete or partial masking of a signal by ambient noise. The existing metric is based on sUAS signals and should be extended to large UAM signals.

Risks. Acoustic metrics that consider ambient noise must ensure that ambient noise models and measurements can provide the level of fidelity required to compute the metric.

5.2.5 Dose Estimation Tool Development, Validation, and Uncertainty Quantification

Section 4.5 presents the hybrid dose estimation method for the preferred test approach. The hybrid method is based on a Kalman filter method that combines the modeled and measured acoustic metrics to produce the best estimate of the true dose and associated uncertainty. The following sections describe the recommended research activities to implement and test the hybrid method.

5.2.5.1 Analytical Method Development

The preferred test approach will recruit survey participants from different types of zones near the vertiport and under enroute flight paths. The hybrid dose estimation method must estimate the dose and associated uncertainty in both zones. The UAM noise and ambient noise characteristics will likely differ between the near-vertiport and enroute zones. NASA should evaluate whether the same hybrid method is optimal for both types of zones. If different noise modeling approaches are used in the two types of zones, the modeling uncertainty must be quantified separately near the vertiport and enroute.

The hybrid dose estimation method developed for X-59 community response testing estimates the single-event acoustic metrics and associated uncertainty corresponding to a single X-59 overflight. The cumulative daily acoustic metrics and uncertainty are based on the sum of each day's single-event metrics and uncertainty. For UAM community response testing, NASA should evaluate whether the hybrid dose estimation method should estimate long-term cumulative metrics based on a sum of estimated single-event metrics or based on combining measured and modeled cumulative metrics directly. The choice will depend on the capabilities of the selected noise models and signal processing methods.

Finally, NASA may consider alternative hybrid dose estimation methods to the Kalman filter method. BRRC evaluated several alternative hybrid methods for X-59, including inverse distance weighting, natural neighbor interpolation, and regression. The Kalman filter method is the mathematically optimal method for combining modeled and measured acoustic metrics under the assumption of Gaussian-distributed errors, but it requires estimates of the modeling and measurement uncertainty. If these uncertainty estimates prove infeasible, NASA may consider the other hybrid methods evaluated for X-59 or an alternative model calibration approach. Whereas the Kalman filter method anchors the outputs of the noise model to the acoustic measurements, a model calibration approach tunes the inputs to the noise model based on the measurements. These methods may have different strengths and weaknesses for UAM noise.

Level of Maturity. BRRC developed the Kalman filter method for X-59 community response testing and showed that it performs better than alternative hybrid dose estimation methods based on simulations.

Risks. The Kalman filter method requires reasonable estimates of the modeling and measurement uncertainty.

5.2.5.2 Uncertainty Quantification

Uncertainty permeates every step of the dose-related activities, from the modeled and measured acoustic metrics to the estimated cumulative doses at survey participants' residences. Understanding uncertainty is critical to the hybrid dose estimation method. The recommended hybrid method, the Kalman filter method, requires knowledge of the uncertainty to combine the modeled and measured acoustic metrics. Furthermore, quantifying the dose uncertainty is critical for developing dose-response models, which are the final products of UAM community response testing.

The modeled acoustic metrics are subject to multiple sources of measurement and modeling uncertainty arising from uncertainty in the input data to the noise models as well as imperfect model formulations. Noise model inputs, including UAM aircraft trajectories and vehicle states, weather conditions, and local terrain, are subject to measurement uncertainty. Furthermore, both integrated and simulation noise models include simplifying assumptions that imperfectly model the governing physics. These sources of uncertainty introduce errors that vary based on the UAM aircraft, operating condition, and distance between the source and receiver. NASA must quantify these sources of uncertainty prior to the UAM community response tests.

The measured acoustic metrics are subject to multiple sources of measurement uncertainty arising from the instrument precision, ambient noise, and localized acoustical effects. Each component of the measurement instrumentation is subject to transducer and calibration uncertainty that may vary with environmental conditions. Although the preferred test approach will employ signal processing methods to separate the UAM signal from the ambient noise, the algorithms cannot perfectly remove time-varying ambient noise from the measured waveforms. Finally, localized acoustical effects such as reflections, diffraction, and shielding from small-scale obstructions may introduce uncertainty when attempting to generalize acoustic measurements at one location to a wider area. NASA must quantify these sources of uncertainty prior to the UAM community response tests.

Level of Maturity. NASA researchers have applied uncertainty quantification methods to X-59 community response testing. Monte Carlo methods and polynomial chaos expansion methods, such as those developed for X-59 (White et al., 2024), are appropriate to propagate uncertainty through noise models. The measurement uncertainty analysis for X-59 (Klos, 2025) is appropriate to evaluate instrumentation and ambient noise uncertainty.

Risks. Uncertainty quantification requires deep knowledge of the noise models and measurement instrumentation. Bias errors in the noise models require accurate validation measurements.

5.2.5.3 Desktop Simulations and Testing

NASA should perform desktop simulations to support the analytical development and uncertainty quantification activities for the hybrid dose estimation method described above. For X-59 community response testing, BRRC built a desktop simulation environment to compare the Kalman filter method to alternative dose estimation methods. The most accurate dose estimation method is the method that produces the lowest error between the estimated and true acoustic metrics. In the real world, the true acoustic metrics are unknowable, but in simulations, the true acoustic metrics are simulated directly. Desktop simulations will enable NASA to evaluate the accuracy of the hybrid dose estimation method by comparing the estimated acoustic metrics with the true acoustic metrics in the simulations.

In BRRC's simulation environment for X-59 community response testing, a smooth reference surface is first created that represents the modeled acoustic metrics on a regular geographic grid. Next, randomly generated modeling errors are added to simulate the true acoustic metrics on the grid, then randomly generated measurement errors are added to simulate the measured acoustic metrics at discrete measurement locations. The simulation then combines the modeled and measured acoustic metrics using the hybrid dose estimation method. Finally, the simulation compares the estimated acoustic metrics with the simulated true values to quantify the accuracy of the dose estimation method. BRRC recommends that NASA adopt a similar simulation approach to evaluate the hybrid dose estimation method for UAM community response testing.

Level of Maturity. BRRC has developed a simulation environment for the Kalman filter method for X-59 community response testing.

Risks. Desktop simulations require realistic representations of modeling and measurement uncertainty.

5.2.5.4 Operational Demonstration

Finally, the hybrid dose estimation method should be field tested with measurements of opportunity at the Los Angeles Olympics in 2028. The Olympics can serve as a dry run for the dual zone test concept, data gathering procedures, noise modeling and measurement methods, and the hybrid dose estimation method with uncertainty quantification. To support ongoing development of the methods, the hybrid method does not need to be applied in real time during Olympics. If the required operational and acoustic measurements are collected during the Olympics, the noise modeling and hybrid dose estimation method can be performed post-test using measured data.

Level of Maturity. The hybrid dose estimation method does not need to be completed by the time of the 2028 Olympics, as it can be applied to measured data afterwards.

Risks. The required acoustic and operational data must be collected during the Olympics to support the hybrid dose estimation method.

5.3 Response-Related Activities

The response-related activities described here are closely coupled with the dose related activities. They encompass research related to:

- How do you ask about UAM annoyance in the presence of other aviation sounds and should the other aviation sources be incorporated as a balanced sampling factor?
- Can you draw a parallel between longitudinal daily annoyance and long-term annoyance? Will a longitudinal study, where you're asking the same people at different times in the presence of different operational tempos, help to quantify those parallels?
- What survey techniques are effective for differentiating between UAM and sUAS?
- What is a list of candidate metrics suitable for UAM annoyance evaluation?
- What is the influence of the ambient environment on the perception of UAM sounds?

5.3.1 Effect of other Aviation Sounds on Test Design and Perception

In the future FAA UAM dose-response test there are likely to be aviation related operations in the vicinity. Developing an effective dose-response test design which takes this into account is critical. The objective is to obtain a nationally representative long-term dose-response relationship for UAM aircraft. The most direct way* is to ask the participants to evaluate their annoyance with UAM noise.

The outcomes from this activity include a field tested survey instruments for annoyance from UAM sounds that differentiate UAM from other aviation sources for both a daily dose and long-term dose. Recommended test strategy, survey procedures and methods to account for the effects of other aviation sounds on balanced sampling for the FAA UAM dose-response test.

UAM Descriptors and Language Differentiating sUAS. UAM might not be a term the public is familiar with. This activity conducts a descriptor study to identify suitable terms appropriate for

* This method was selected by BRRC and is in our preferred approach. It is feasible other test designs could examine annoyance differentials between aircraft and aircraft + UAM with different sampling and survey options to arrive at the isolated UAM dose-response. Those concepts are not addressed in this document.

asking participants about their annoyance from UAM sounds. The terminology needs to differentiate vehicles that may be in their soundscape. Are there differences in terminology near the vertiport environment vs. enroute segments due to the different sounds / characteristics / qualities in the different modes of flight? What is the appropriate language to use in the survey instruments to capture UAM perception?

Given the prevalence of hobbyist drones and the introduction of UAS package delivery services, many people in the US are exposed to noise from sUAS operations. Is there a way to ask the 'bother, disturb or annoy' question that differentiates UAM from sUAS vehicles as the noise source? A test evaluating the effectiveness of differentiating between sUAS and UAM noise is needed. The intended dose-response relationship is for UAM noise, and our preferred approach test skeleton suggests that the response question is structured to directly ask for UAM noise. This activity will lean on the results of the UAM and sUAS descriptors and language test.

A language descriptor laboratory study can be developed to identify suitable wording and enable subsequent development of the survey instrument. Survey questions for the future FAA UAM dose-response test can be developed that differentiate UAM from sUAS sounds. The new survey instruments can be tested in the laboratory, patterned after Christian and Cabell (2017) to examine the response relationship between UAM and other aviation sounds.

Assessment of regional differences in language is a concern. The survey instrument will need to be tested and use of a remote testing method like the VANGARD process (Federal Register, 2025) could be employed in different regions to assess the suitability of the survey language. The NASA VANGARD test (or subsequent tests using that methodology) is an excellent opportunity to gather some preliminary data about UAM perception. It is not clear if the sounds presented to the participants will include ambient background sounds and if those presented sounds are linked to the presumed ambient location of the participant. The investigation of objective parameters listed in the Federal Register notice (sound quality metrics, spectra, sound exposure level and amplitude envelope shaping) will provide insights for single event metrics and can be leveraged in future test planning. A discussion of ambient noise activities is included in Sections 5.2.4 and 5.3.4 and should be incorporated to the degree possible.

Should remotely administered tests target both (a) the communities where FAA will eventually survey and (b) communities very different from the surveyed communities to see how "nationally representative" the results may be? Considerations should be given to testing in areas without UAS operations to avoid contaminating a future FAA UAM dose-response survey area.

The ultimate test of the survey instrument will be with a population whose residential locations are exposed to UAM noise. A prime opportunity is the Olympics in 2028. With recruitment based on the dual zone approach as described in the BRRC preferred approach, this test can yield insights about the necessity of including cruise vs. vertiport regions in the sampling strategy. Since the Olympics are only a few weeks long, the survey instruments will need to ask daily if the participant was 'bothered, disturbed or annoyed today' in addition to a single annoyance question 'over the last year.' The daily survey will also need to include a question about their times at home so that the exact dose can be evaluated. This will also inform the operational steadiness activity described below.

Influence of sUAS Familiarity on Annoyance. People's existing beliefs about this new class of UAM vehicles might be influenced by their interactions with consumer-grade / hobbyist drones or drone-delivery services. Do interactions and familiarity with sUAS vehicles influence how people perceive the sound from UAM vehicles in their neighborhoods? Suitable questions for the background survey should be developed, including asking about familiarity—whether they own one or have a UAS operator license. A remote survey test (perhaps coupled with the UAM descriptor activity), should be administered to test the survey instrument and assess regional differences. The ultimate survey test is at the Olympics.

Influence of Other Aviation Noise Sources on UAM Annoyance. The objective of this activity is to identify the degree of annoyance and performance of the UAM sounds relative to other aviation and transportation noise sources such as helicopter, general aviation, propeller and fixed wing commercial and military aircraft. Development of the eventual dose-response relationship will require quantification of the response uncertainty (as well as the dose uncertainty). NES included both civil and military flight ops radar data in the INM DNL calculations and it is likely that such operations will be present in the FAA UAM dose-response communities. It may be possible to develop a laboratory test that can differentiate the responses from the vehicle contributions to help quantify response uncertainty.

Balanced Sampling. Another aspect for understanding the relationship of response to different aviation noise sources is to inform factor identification for the balanced sampling for the FAA UAM dose-response testing. NES relied on the aircraft fleet mix ratio between commuter and large jet aircraft flight operations. Does a similar balancing factor, (such as the ratio of UAM operations to the remainder of the operational fleet at that location) need to be included for UAM annoyance? Understanding the projected operational landscape across the US based on the operational scenario analysis will help make this determination.

Depending on the location of the UAM flights and their proximity to other aviation operations, the Olympic testing might be an opportunity for gathering a limited dataset with some differences in fixed wing vs. UAM flight exposures. It is possible that the test could be inconclusive to a lack of data.

Level of Maturity. Techniques for administering laboratory tests and surveys are well established.

Risks. There is a significant probability that the public is not familiar with language that differentiates between UAM and sUAS vehicles. As a risk mitigation strategy, it might be necessary to develop some clarifying training materials that are administered as part of the survey. There could be significant regional differences in language differentiating UAM and sUAS necessitating additional survey instrument development and repeated testing.

5.3.2 Effect of Operational Steadiness on Long-Term Response

The activity needs to explore the question: what duration of operational exposure is required for a dose-response to be considered long term? During the expected FAA UAM dose-response testing it is plausible that the operational tempo will not be steady for a full year, concurrently at each of the survey communities.

This activity involves development and execution of suitable test designs and examination of potential statistical analysis methods. One specific test is a daily dose-cadence test in people's homes and b) development of test strategy recommendations for the design and post-test analysis for the future FAA UAM dose-response test (with longitudinal daily dose and long-term annual dose assessments).

Strategy and Tested Reduced Duration Survey Question. The first objective is to develop a method and test a new associated survey question that asks about durations less than a year, and are commensurate with a reduced steady state operational tempo time period.

One hypothesis is that the survey question can be modified to ask about reduced duration exposure time (e.g., 'over the last few months' instead of 'over the last year') and the dose-response answer is representative of long-term annoyance.

Fields and Powell (1984) conducted a controlled experiment of helicopter annoyance with deliberate flights over 17 test days with up to 32 flights a day. They surveyed people daily and asked about their time at home and had relevant information about the helicopter operations, so they were able to compute an individualized daily "at home" noise exposure. They noted that "there was some evidence that the single day annoyance scores increased in the first days of the survey." This suggests that surveying immediately after an operational cadence change might not be reflective of long-term response.

It is not immediately clear how to conduct either a laboratory or in situ study to assess dose response over these differing time scales. The USAF sponsored a "own-home" study on the effect of low-altitude, high-speed overflights (Stusnick et al., 1993) This study utilized audio playback systems within each participant's house. Overflight noise events were played at various levels and cadences, and the participants completed daily questionnaires about the events and their responses to them. This study helped to determine that the busy month was the appropriate time scales for assessing their annoyance to these overflight events.

It might be possible to structure a similar test (with current technology) that includes deliberate changes in the operational cadence and asks about daily annoyance. UAM sounds can leverage the database of UAM sounds developed under Task 2.3.2 Desktop Synthesis and Testing to generate auralized sounds for testing.

In the Fields helicopter survey (1984) they asked daily for an annoyance judgment. They also had a single 'over the last year' annoyance question. Unfortunately, they didn't have sufficient data to compute the annual long-term dose so couldn't directly compare with the daily dose-response. However, they conducted a multi-regression analysis which "removed the effect of noise level" and showed that the study day variable was not statistically significant for this study, but they noted that they found enough evidence to recommend that study day variable be considered in the design of future studies. The intent of BRRC's preferred test design which conducted longitudinal surveys repeatedly with the same survey participants over the course of a year, at selected times some period after cadence changes, will lend insight on this question.

Statistical Methods for Applying Trends from Changing Steadiness. The second objective is to develop statistical methods that will permit application of trends from daily annoyance to long-term annoyance even if operational tempos are changing.

A secondary hypothesis: the trends in a longitudinal dose-response test parallel the daily dose-response slope at a given operational tempo level. Even if the annoyance values are not directly comparable, the comparison can be used to quantify the uncertainty in the long-term dose response based on the change in operational tempo over the long-term (one year) test duration. This will have an influence on future test design. In the preferred approach, for the longitudinal daily dose study, for each subsequent test, the same person will be exposed to a different dose range. There is some power in that because it is a longitudinal design with the same person providing annoyance responses to a different collection of dose ranges for each test. The operational scenario analysis data can be leveraged for development of the statistical methods.

A long-term dose-response test probably is needed to explore this topic definitively. That is why the BRRC preferred approach is to conduct a longitudinal daily dose response test in conjunction with the long-term dose response test (single survey). The daily dose-response relationship can also help the FAA effectively articulate science-based threshold levels for future policy and regulatory use.

Level of Maturity. Survey test design and statistical analyses are well established. Technology preparation for an 'in home' test will need to be refreshed but the concept has been demonstrated.

Risks. The possibility of showing a direct, predictable link between daily response and long-term response is uncertain. The expectation is that in the absence of methods to quantify the link, inferences can be drawn from the trends – enough to quantify response uncertainty for the future FAA UAM dose-response test.

5.3.3 Metrics and the UAM Dose-Response Relationship

The activity needs to explore the question: what acoustic metrics align with people's annoyance judgments from UAM noise? Although the objective for the final dose-response relationship is to utilize DNL as the noise exposure metric, additional metrics may help to inform annoyance response to UAM noise.

Single Event Metric Lab Study. This activity involves listener trials to examine the correlation between annoyance judgments and various single event metrics. The results from these listener trials will provide the validation of using SEL as the primary single event metric, or point to using additional metrics to adjust SELs and the resulting DNL values (like the onset-rate adjusted SEL penalty used by DoD).

Candidate Cumulative Metrics in Addition to DNL. In addition to single event metrics, a list of viable and promising cumulative noise exposure metrics needs to be identified for analysis of the FAA UAM dose-response tests. The primary metric is a DNL based on a 24-hour average day. Other metrics include the generalized cumulative noise exposure metric (Vaughn & Christian, 2024), L_{eq}, and Number of Events Above, as well as different time-basis for DNL such as busy day or busy month. The Olympics provides a measurement opportunity to evaluate cumulative daily metrics.

A key outcome of this activity is a document recommending metrics and survey questions for use in the future FAA UAM dose-response test. Along with documented research findings, the recommendations should be considered for submittal to standards organizations for adoption.

Level of Maturity. NASA is well versed in conducting listener trials and understands the range of noise metrics that apply to UAM. The small challenge will be the range of realistic UAM noises to be used in the trials, but this range should be solidified as OEMs switch from prototype UAM vehicles to production designs. From this transition, a quality pool of noise waveforms will be available to NASA.

Risks. The risk of this activity is small because of the maturity of the testing approach.

5.3.4 Influence of the Ambient Environment on Perception of UAM Sounds

The activity needs to explore the question: what influence does ambient noise have on people's annoyance judgments from UAM noise?

Lab Study of UAM Noise in Realistic "At Home" Ambient Sounds. NASA should conduct a listener trial to evaluate the effect of ambient noise on annoyance judgments. The ambient noise characteristics will be defined by efforts under Section 5.2.4.1. This evaluation may lead to a validated discounted annoyance that accounts for the influence of ambient noise on the detection and response to UAM signals (Rizzi et al., 2025).

Survey Questions for Characterization of "At Home" Ambient Sounds. The outcome of the listener trial will support developing recommended survey questions that capture participants' ambient noise environments and development of monitoring requirements for determining ambient noise characteristics. The monitoring requirements will assess the appropriate ambient-aware metrics needed, and define the required ambient noise metrics, sampling rates, and frequency range that are needed for metric evaluation. The survey questions may include questions about the audibility and noticeability of UAM noise as well as questions about the existing ambient noise environment at participants' residences. The survey test questions can be tested in the laboratory or at the Olympics test prior to the future FAA UAM dose-response tests.

Level of Maturity. NASA is well versed in conducting listener trials and the range of ambient noise environments will be defined under Section 5.2.4.1 efforts. The small challenge will be the range of realistic UAM noises to be used in the trials, but this range should be solidified as OEMs switch from prototype UAM vehicles to production designs. From this transition, a quality pool of noise waveforms will be available to NASA. The monitoring requirements will be defined under Section 5.2.4.3 efforts.

Risks. The risk of this activity is small because of the maturity of the testing approach and the leveraging of additional efforts outlined in Section 5.2.4.

5.4 Other Activities

5.4.1 Early Field Test Opportunities

Measurements in the UAE and Other Locations. These could provide opportunities for source characterization but will require significant advanced coordination to understand the projected operations, vehicles, and timelines. We believe that monitoring these evolving opportunities will be important to determine if any suitable targets of opportunity arise.

Los Angeles Olympics. BRRC has identified the 2028 Summer Olympics in Los Angeles (14-30 July 2028) as a key measurement of opportunity. Many activities incorporate this opportunity in the roadmaps and include:

- Operational evaluation and prediction of UAM noise levels in nearby communities
- Coordination and outreach with officials and recruitment of test partners/collaborators
- Test plan design for a dual zone daily annoyance dose-response test
- Flight trajectory and vehicle operating state gathering procedures
- Test plan for noise monitoring technology, source characterization, and model validation
- Execution of the test plans
- Post test analysis and validation, dissemination of lessons learned
- UAM descriptors and language differentiating sUAS
- Influence of other aviation noise sources on UAM annoyance
- Candidate cumulative metrics in addition to DNL
- Survey instrument for characterization of "at home" ambient sounds
- Measurement data acquisition for validation of the ambient noise model
- Evaluation of ambient-aware metrics on annoyance response

Level of Maturity. The process of coordination and test planning activity is mature, though coordination with authorities, Olympic officials, and UAM operators specific to this testing opportunity will need to be initiated and evolve. Testing concepts and practical execution for UAM measurements in an urban setting are not yet well established. The various technologies to be tested (e.g., noise monitoring, UAM survey administration) are not yet mature, and testing will be important for risk reduction for the future FAA UAM dose-response test in various locations around the US.

Risks. Securing permission to conduct measurements and surveys is a long lead item and coordination with authorities could identify significant hurdles (technical or political). A significant risk is scope creep and taking advantage of too many opportunities during the Olympics. The early coordination and planning could be challenging depending on the maturity of the detailed Olympic plans as they relate to the UAM operations. Conducting in situ measurements in urban areas has several risks related to site access, equipment security, and potential for significant late changes from the planned Olympic activities (e.g., changes to UAM operational plans). The key will be to remain flexible and have identified several backup plans with sufficient details to be able to adapt while successfully conducting the testing.

5.4.2 Coordination / Standards and Guidance / Technical Reviews

Many of the tasks described in the dose and response-related activities require coordination with external entities (see Table 6). Coordination serves different purposes including:

- Test planning in locations external to NASA facilities
- Enabling external partnerships and collaboration for technical activities
- Technical reviews
- Stakeholder coordination, review and feedback

- Dissemination of new methods, guidance, protocols and best practices

In the context of this document, stakeholders include organizations that are affiliated with the UAM industry and entities that could be involved in the future FAA UAM dose-response testing (OEMs, operators, contractors, researchers, academia). Other coordinating entities are described in the scoping document and reviewed in Section 2.6 where we suggested a new category "Technical Groups" consisting of technical societies. For all activities NASA should be coordinating with the FAA as described in the scoping document, so they are not listed explicitly.

Table 6. Activities and Milestones that Identify External Coordination / Reviews

Dates	Task	Description	Entities
Y1-Y3	All	Measurements of Opportunity in the UAE and elsewhere	Local officials, OEMs, collaborators
Y1-Y3	All	Olympic measurements of opportunity: coordination for initial feasibility exploration and test planning and execution purposes	Olympic/local officials, OEMs, collaborators
Y1Q	1	Establish the operational scenario database structure	Stakeholders
Y1Q2	1	Operational scenario data gathering, stakeholder review, and data finalization	Stakeholders, OEMs, Tech. Societies
Y2Q4	2.1.3	Acoustic modeling best practices and guidelines	Standards orgs, Stakeholders, OEMs, Tech. Societies
Y1Q4	2.2.1	Draft acoustic source data development procedures and best practices document	Standards orgs, Stakeholders, OEMs
Y1Q4	2.2.1	Data development plan for the UAM vehicles of interest	OEMs
Y3Q4	2.3.4	Recommended protocols for extracting UAM sounds from the ambient	Standards orgs, Stakeholders, OEMs, Tech. Societies
Y3Q4	2.5.4	Dose evaluation estimation method, validation results	Standards orgs, Stakeholders, OEMs
Y3Q4	3.3.2	Recommended metrics for the FAA UAM dose-response test	Standards orgs, OEMs, Tech. Societies
Y3Q4	3.1.1	UAM descriptors and language differentiating sUAS	Stakeholders, OEMs
Y3Q4	3.2.1	Recommended time period survey question and daily response testing strategy	Standards orgs, Stakeholders, OEMs
Y3Q4	3.3.2	Candidate cumulative metrics in addition to DNL	Standards orgs, Stakeholders, OEMs
Y3Q4	3.4.2	Verified and tested survey instrument re: ambient "at home"	Stakeholders, OEMs, Tech. Societies
Y3Q4	3.4.3	Ambient noise measurement recommendations	Standards orgs, Stakeholders, OEMs
Y3Q4	All	Post Olympics lessons learned dissemination	Stakeholders, OEMs, Tech. Societies

6 RESEARCH ROADMAP

A technical research roadmap is described in this section of the report.

The research activities are initiated with an operational scenario analysis. This is a projection of the future UAM operations and is critical for development of the future FAA UAM dose-response test plan. This information also guides the research activities and priorities, and the data is leveraged in several of the activities.

Dose-related activities comprise a significant portion of our analysis and include such development of community noise modeling tools, methods to acquire source data for the models, techniques for extracting UAM signals from measured data in non-ideal circumstances, discussion of ambient tool development and a dose estimation tool development activity using a Kalman filter approach.

Response-related activities target the effect of other aviation sounds on test design and perception, methods to assess the effect of operational steadiness on long-term response, human response metrics and the influence of the ambient environment on UAM perception. This section closes with a summary of possible activities for an early testing opportunity at the Los Angeles Olympics and recommendations of activities with coordination and external stakeholder involvement.

A three-year research plan has been developed, and a high-level overview is provided in Figure 7. The start of the research is assumed to be in April 2026. Main categories of activities are identified, with the duration of each category portrayed by the colored cells.

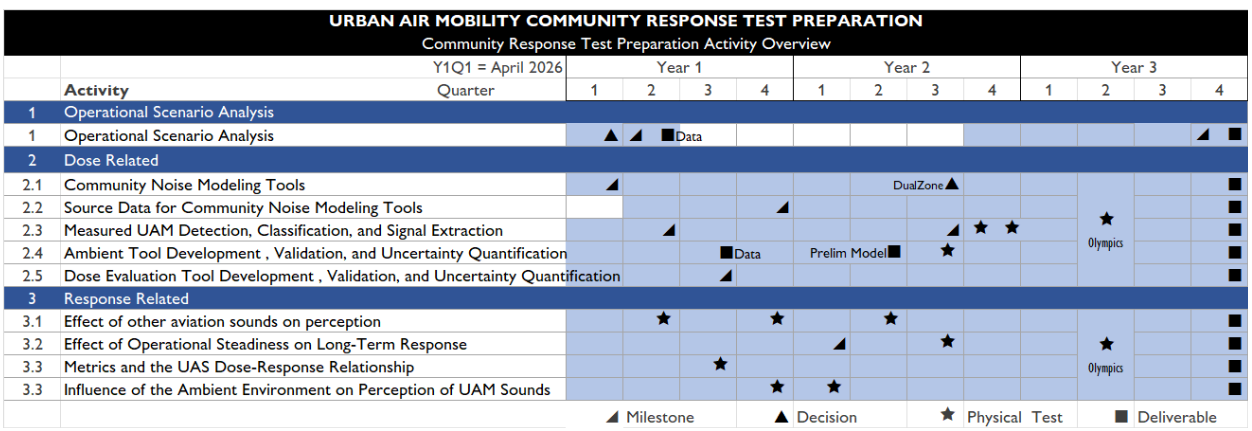

Figure 7. Community Response Test Preparation Timeline Overview

6.1 Operational Scenario Analysis

The operational scenario analysis (A1) supports both dose and response-related research and needs to be initiated immediately. The analysis should be refined as new data and projections are available. An early decision about the database structure (A1, Y1Q1) should be made in consultation with other stakeholders and in consideration of the noise model requirements. The Y1Q2 deliverable is a projection of future operational scenarios and should be shared.

A significant deliverable at the end of Year 3 (Deliverable A.1) is an updated UAM operational scenario database that will inform the FAA about the future UAM operational landscape (location, timing, communities exposed to noise) and will support detailed design of the UAM dose-response testing.

A corresponding list of the milestones, physical tests, decisions and deliverables is provided in Table 7

Table 7. Operational Scenario Roadmap Milestones, Physical Tests, Decisions and Deliverables.

Milestones	Date	Description
A1	Y1Q1	Draft operational scenario database to stakeholders for review
A1	Y1Q4	Draft updated operational scenario to stakeholders for review
Physical Tests		
Decisions		
A1	Y1Q1	Operational scenario database structure decision
Deliverables		
A1	Y1Q2	Operational scenario data for analysis and test design
A1	Y1Q4	Updated operational scenario data for FAA dose-response planning
Dependencies		

Exit Criteria: A Stakeholder reviewed UAM operational scenario analysis database for the anticipated time period of the FAA dose-response test has been prepared.

6.2 Dose-Related Activities

A detailed schedule for dose-related activities is provided in Figure 8. The activities are grouped together and discussed in detail in the following sections:

- Section 6.2.1 Community Noise Modeling Tools
- Section 6.2.2 Source Data for Community Noise Modeling Tools
- Section 6.2.3 Measured UAM Detection, Classification, and Signal Extraction
- Section 6.2.4 Ambient Tool Development, Validation, and Uncertainty Quantification
- Section 6.2.5 Dose Evaluation Tool Development, Validation, and Uncertainty Quantification

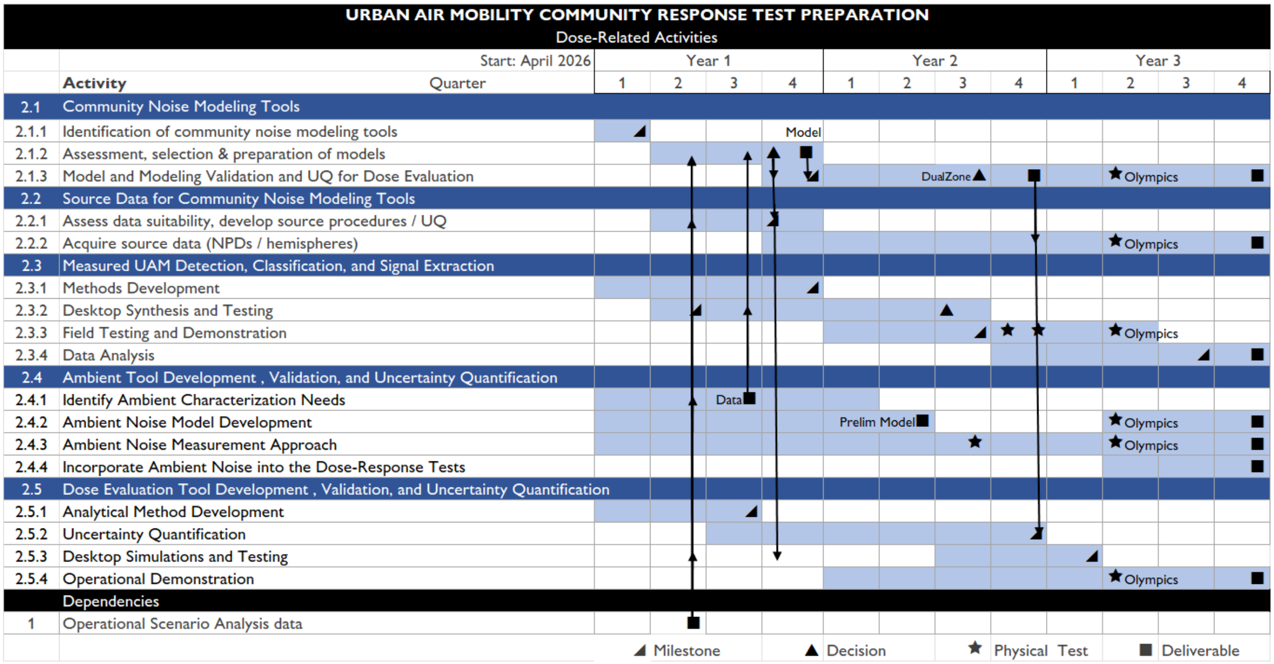

Figure 8. Dose-Related Analysis and Tools Timeline

6.2.1 Community Noise Modeling Tools

The primary goal of this activity is to develop and release a set of validated and documented models suitable for use in the FAA UAM dose-response test. A graphical representation of these activities is provided in Figure 8. A corresponding list of the milestones, physical tests, decisions and deliverables is provided in Table 8.

Exit Criteria: With the models verified and understood and the uncertainties quantified, they can be provided to stakeholders for evaluation. The activity is envisioned to have periodic deliverables of models (at the end of each year) to coincide with the development activities and to provide time for addressing feedback from stakeholders. The final validated and documented models suitable for use in the FAA UAM dose-response test should be released at the end of this activity.

Table 8. Community Noise Modeling Tools Roadmap Milestones, Physical Tests, Decisions and Deliverables.

Milestones	Date	Description
2.1.1	Y1Q1	Short list of candidate noise modeling tools
2.1.3	Y3Q4	Validated and released modeling tools and quantified uncertainties
Physical Tests		
	Y3Q2	Olympics test to obtain noise model validation data
Decisions		
2.1.2	Y1Q4	Selection of models for continued development
2.1.4	Y2Q3	Decision about proceeding with the dual zone testing strategy
Deliverables		
2.1.2	Y1Q4	Noise models
2.1.3	Y2Q4	Improved noise models including dual zone model
2.1.3	Y3Q4	Validated noise models and quantified uncertainties
Dependencies		
1	Y1Q2	Operational scenario analysis database
2.4.1	Y1Q3	Ambient noise database

6.2.2 Source Data for Community Noise Modeling Tools

The primary objective of this activity is the development and release of validated source acoustic models for use in the noise tools developed under the Community Noise Modeling Tools Activity. A graphical depiction of this activity is in Figure 8. The data from the operational scenario analysis (A1, Y1Q2) will be used to guide the source data suitability assessment activity. Initially a broader look at data will ensue, but the short list of noise models requiring data development and validation will be those identified in activity B1.2. A corresponding list of the milestones, physical tests, decisions and deliverables is provided in Table 9.

Exit Criteria: The primary outcome is validated and released acoustic source data for the noise models developed under Task B1.

Table 9. Source Data Milestones, Physical Tests, Decisions and Deliverables.

Milestones	Date	Description
2.2.1	Y1Q4	Draft source data development procedures/best practices document
2.2.1	Y1Q4	Data development plan for UAM vehicles of interest
Physical Tests		
2.2.2	Y3Q2	Olympics – obtain source data
Decisions		
Deliverables		
2.2.2	Y3Q4	Validated noise model acoustic data with quantified uncertainties
Dependencies		
1	Y1Q2	Operation Scenario Analysis Data
2.1.2	Y1Q4	Selected noise models

6.2.3 Measured UAM Detection, Classification, and Signal Extraction

The primary goal of this activity is to develop, test and validate methods for extracting the UAM sounds from acoustic measurement data. The research schedule is shown in Figure 8 and includes the four primary activities: methods development, desktop synthesis and testing, two field tests and a demonstration, and data analysis. A corresponding list of the milestones, physical tests, decisions and deliverables is provided in Table 10.

Exit Criteria: The primary outcome is a recommended, validated and demonstrated methodology for detection, classification and signal extraction of UAM sounds in realistic environments.

Table 10. Measured UAM Detection, Classification, and Signal Extraction Milestones, Physical Tests, Decisions and Deliverables.

Milestones	Date	Description
2.3.1	Y1Q4	Developed methods for detection/classification/signal extraction
2.3.3	Y2Q3	Field test strategy and plan
2.3.4	Y3Q3	Technology demonstration results and lessons learned
Physical Tests		
2.3.3	Y2Q4	Field Tests
2.3.3	Y3Q2	Olympics – Demonstration of UAM noise monitoring technology
Decisions		
2.3.2	Y2Q3	Down select methods for field testing and demonstration
Deliverables		
2.3.4	Y3Q4	Recommended methodology and protocols
Dependencies		
2.4.1	Y1Q3	Recorded ambient database of “at home” environments

6.2.4 Ambient Tool Development, Validation, and Uncertainty Quantification

The primary goal of this activity is to assess the influence of ambient noise on both the received dose and response, developing the data and inputs for the inclusion of ambient noise in the prediction of UAM noise exposure, and documenting this process. The research schedule is shown in Figure 8 and includes the five primary activities: Quantify ambient noise at home, modeling, define ambient noise influence on dose-response relationship, and develop the data and inputs for noise exposure model tool. A corresponding list of the milestones, physical tests, decisions and deliverables is provided in Table 11.

Exit Criteria: The primary outcome is a recommended, validated and demonstrated methodology for the inclusion of ambient noise influence on the received dose and corresponding response.

Table 11. Ambient Tool Development, Validation and Uncertainty Quantification Milestones, Physical Tests, Decisions and Deliverables.

Milestones	Date	Description
2.4.1	Y1Q3	Quantify statistical structures for received ambient noise
2.4.2	Y2Q2	Ambient modeling procedures
Physical Tests		
2.4.4		Subjective dose-response tests on ambient noise influence
Decisions		
Deliverables		
2.4.2	Y3Q4	Ambient noise modeling tool
Dependencies		
2.4.1	Y1Q2	Operation scenario analysis data

6.2.5 Dose Evaluation Tool Development, Validation, and Uncertainty Quantification

The primary goal of this activity is to evaluate, quantify, and develop the dose exposure tool. The research schedule is shown in Figure 8 and includes the five primary activities: methods development, uncertainty quantification, desktop synthesis and testing, a demonstration, and application delivery. A corresponding list of the milestones, physical tests, decisions and deliverables is provided in Table 12.

Exit Criteria: The primary outcome is a validated and demonstrated dose noise modeling tool.

Table 12. Dose Evaluation Tool Development, Validation, and Uncertainty Quantification Milestones, Physical Tests, Decisions and Deliverables.

Milestones	Date	Description
2.5.1	Y1Q3	Hybrid dose estimation method
2.5.2	Y2Q4	Uncertainty quantification with updated model validation
2.5.3	Y3Q2	Desktop simulation based on ??
Physical Tests		
2.5.4	Y3Q2	Olympics dose estimation and UQ
Decisions		
Deliverables		
2.5.4	Y3Q4	Validated Kalman dose estimation model
Dependencies		
2.1.3	Y2Q4	Model and Model Validation and UQ for Dose Evaluation

6.3 Response-Related Activities

A detailed schedule for response-related activities is provided in Figure 9. The activities are grouped together and discussed in the following sections:

- Section 6.3.1 Effect of other Aviation Sounds on Test Design Perception
- Section 6.3.2 Effect of Operational Steadiness on Long-Term Response
- Section 6.3.3 Metrics and the UAS Dose-Response Relationship

- Section 6.3.4 Influence of the Ambient Environment on Perception of UAM Sounds

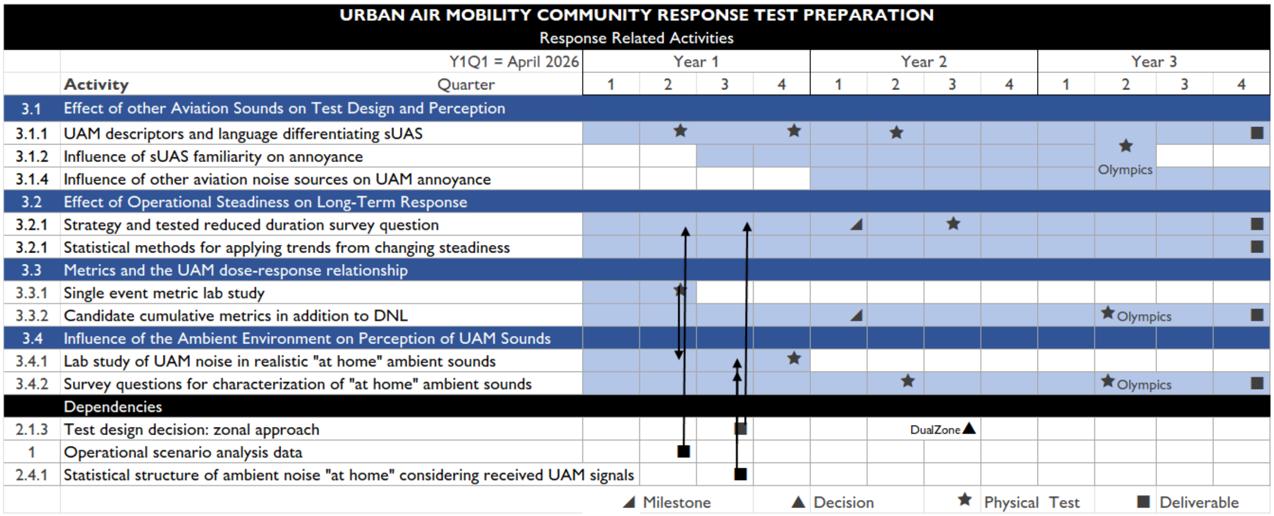

Figure 9. Response-Related Analysis and Tools Timeline

6.3.1 Effect of other Aviation Sounds on Test Design Perception

The primary objective of these activities is to understand the relationship between UAM and sUAS perception, have appropriate descriptors for use with the public and to have tested survey instruments that isolate the annoyance response to UAM vehicles. A corresponding list of the milestones, physical tests, decisions and deliverables is provided in Table 13.

Exit Criteria: Field tested survey instruments for annoyance from UAM sounds that differentiate UAM from other aviation sources for both a daily dose and long-term dose. Recommended test strategy, survey procedures and methods to account for the effects of other aviation sounds on balanced sampling for the FAA UAM dose-response test.

Table 13. Effect of other Aviation Sounds Milestones, Physical Tests, Decisions and Deliverables

Milestones	Date	Description
3.1.1	Y3Q4	Field tested UAM annoyance survey instrument
3.1.2	Y3Q4	Survey UQ regarding UAM vs. other aviation sounds
3.1.3	Y3Q4	Necessity of including ‘other aviation sounds’ in balanced sampling
Physical Tests		
3.1.1	Y1Q2	UAM and sUAS language descriptor lab study
3.1.1	Y1Q4	UAM and other aviation sounds differential lab test
3.1.1, 3.1.2	Y2Q2	Remote test of survey instrument to assess regional differences
3.1.1, 3.1.2, 3.1.3	Y3Q2	Olympic UAM dual zone survey test
Decisions		
Deliverables		
3.1.1	Y3Q4	UAM descriptors and language differentiating sUAS
Dependencies		
2.1.3	Y1Q3	Test design decision: zonal approach

6.3.2 Effect of Operational Steadiness on Long-Term Response

The two primary objectives are 1) develop a long-term survey strategy and survey question that asks about a time-period commensurate with operational tempo changes that yields a long-term response and 2) conduct an in-home survey test that quantifies the relationship between daily and long-term annoyance.

A corresponding list of the milestones, physical tests, decisions and deliverables is provided in Table 14.

Exit Criteria: Recommendation for a suitable duration survey question and daily dose testing strategy that reflects long-term annoyance despite periodic changes in operational tempo.

Table 14. Effect of other Operational Steadiness Milestones, Physical Tests, Decisions and Deliverables

Milestones	Date	Description
3.2.1	Y2Q1	Prepared technology and design of an in-home dose-response test
Physical Tests		
3.2.1	Y2Q3	In-home dose-response test for UAM
Decisions		
Deliverables		
3.2.1	Y3Q4	Recommended time period survey question and daily response testing strategy
Dependencies		
2.3.2	Y1Q3	Desktop synthesized signal and ambient data for auralization
1	Y2Q2	Operational scenario analysis data

6.3.3 Metrics and the UAS Dose-Response Relationship

The primary objective of this activity is to develop a recommended list of single event noise metrics for the future FAA UAM dose-response test. As noted in Section 5.3.3, this exploration can leverage laboratory testing.

A corresponding list of the milestones, physical tests, decisions and deliverables is provided in Table 15.

Exit Criteria: Recommend list of single event noise metrics and rationale.

Table 15. Metrics and the UAS Dose-Response Relationship Milestones, Physical Tests, Decisions and Deliverables

Milestones	Date	Description
3.3.2	Y2Q1	Candidate cumulative metrics in addition to DNL
Physical Tests		
3.3.1	Y1Q2	Lab study – single event metrics
3.3.2	Y3Q2	Olympics – metric evaluation
3.3.3	Y1Q3	sUAS vs. UAM differentiation survey test
Decisions		
Deliverables		
3.3.2	Y3Q4	Recommended metrics for the FAA UAM dose-response test
Dependencies		
2.4.1	Y1Q3	Statistical structure of ambient noise "at home" considering received UAM signals
1	Y1Q2	Operational Scenario Analysis data

6.3.4 Influence of the Ambient Environment on Perception of UAM Sounds

This activity will evaluate perception of UAM sounds in the presence of a realistic ambient. It includes laboratory testing which leverages ambient database and statistical descriptions of ambient sounds "at home" developed under dose-related activity described in Section 5.2.4.1.

A corresponding list of the milestones, physical tests, decisions and deliverables is provided in Table 16.

Exit Criteria: Recommended survey questions regarding ambient noise, audibility and noticeability of UAM noise and corresponding description of ambient noise characteristics to inform ambient noise monitoring requirements.

Table 16. Influence of the Ambient Environment on Perception of UAM Sounds Milestones, Physical Tests, Decisions and Deliverables

Milestones	Date	Description
Physical Tests		
3.4.1	Y1Q4	Lab study of UAM noise in realistic "at home" ambient sounds
3.4.2	Y2Q2	Survey questions for characterization of "at home" ambient sounds
3.4.2	Y3Q2	Olympics – survey instrument test
Decisions		
Deliverables		
3.4.2	Y3Q4	Verified and tested survey instrument re: ambient "at home"
Dependencies		
2.4.1	Y1Q3	Statistical structure of ambient noise "at home" considering received UAM signals
1	Y1Q2	Operational Scenario Analysis data

6.4 Other Activities

6.4.1 Early Field Test Opportunities

A specific timeline for an Olympic test has not yet been established. But timeframes for activities leading up to these measurements of opportunity will include:

- Year 1 – Coordination with local authorities, Olympic officials, and UAM operators
- Year 1 – Operational assessment and acoustic evaluation
- Year 1 – Identification of testing goals and development of a testing strategy
- Year 2 – Detailed test planning
- Year 3 – Test execution, post-assessment, data test analysis and validation activities

Exit Criteria. Successful execution of the Olympic test plan. Post test analysis completed, documented and test data released. Lessons learned documented and disseminated.

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Appendix E HMMH/Westat Final Report

Independent Technical Review by the HMMH Team of NASA Scoping Document for Urban Air Mobility Community Response Test Preparation

July 2025

Prepared for:

NASA via Analytical Mechanics Associates
21 Enterprise Parkway
Suite 300
Hampton, VA 23666

Prepared by:

Brandon L. Robinette
Joseph J. Czech

Harris Miller Miller & Hanson Inc.
700 District Ave, Suite 800
Burlington, MA 01803

Andreea Erciulescu, PhD
David Cantor, PhD
Eric Jodts
Hannah Popick

Westat
1600 Research Boulevard
Rockville, MD 20850

HMMH Report No: 23-0385.001.001

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1 Introduction

The National Aeronautics and Space Administration (NASA) envisions the Federal Aviation Administration (FAA) conducting community response testing (CRT) in the 2030 timeframe[1] to develop a nationally representative long-term dose-response relationship for larger emerging technology aircraft (ETA), i.e., urban air mobility (UAM) aircraft or air taxis. As a possible future technical challenge for NASA's Revolutionary Vertical Lift Technology (RVLT) Project, NASA prepared a scope for preparation of a UAM CRT ("Scoping Document"; NASA, 2025a). Contracted through Analytical Mechanics Associates (AMA), Harris Miller Miller & Hanson Inc. (HMMH) has teamed with Westat, Inc. (Westat) to provide an independent technical review (ITR) of the Scoping Document. This report serves as the HMMH Team's ITR, one of three ITRs specifically sought by NASA.

Sections 2 through 7 address each of the six tasks required by NASA/AMA, respectively. Section 8 provides general comments about the Scoping Document, and Section 9 contains the bibliographical information for the references cited herein. As mentioned in Section 7, this report is accompanied by an electronic Microsoft Project file for the requested Gantt chart.

[1] With admitted timeframe uncertainty, NASA envisions the CRT to start in 2030 "when certificated UAM vehicles are flying commercial operations over populations for extended periods of time."

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2 Task 2.2.1 - Missing or Unnecessary Activities

This section identifies activities that are either missing (not represented in the Scoping Document) or that are unnecessary and provides the associated rationale. Section 2.1 addresses the missing activities, and Section 2.2 addresses the unnecessary activities.

2.1 Missing Activities or Considerations

Each of the following paragraphs mentions an activity or consideration the Scoping Document had missed. The primary idea of each 'miss' is bolded.

Regarding Section 4A(ii)(c) which states, "The [Neighborhood Environmental Survey] NES noise estimates were based on aircraft flight data, including aircraft state, weight, configuration, other state data, and flight tracks", it should be noted that **aircraft performance modeling** comparable to that built into the FAA's Environmental Design Tool [AEDT; or its predecessor the Integrated Noise Model (INM)] is unlikely to exist in UAM noise models available for use at the time of this study. Some required UAM modeling data will likely be obtainable independent of aircraft Original Equipment Manufacturers (OEMs) and vertiport operators, such as numbers of annual flight operations and flight tracking data through recording of Automatic Dependent Surveillance-Broadcast (ADS-B) data or other sources. Other required modeling data, such as aircraft configuration/trim state during various flight phases, will most likely need to be collected in coordination with aircraft OEMs and vertiport operators/pilots. Such data will also likely need to be generalized for application to modeling aircraft along recorded flight trajectories, as collection of flight system data for individual flights over the course of a year is unlikely to occur.[2] So, unlike the NES which was able to be executed independent of cooperation from airports (Miller et al., 2021), aircraft manufacturers, airlines, and pilots, this study will likely necessitate cooperation with some of the equivalent entities for UAM operations.

Regarding Section 4C(i)(a), Time (at or) Above an A-weighted Maximum Sound Level Threshold (**TA**) should also be considered, in addition to time of day.

Regarding Section 5A Analysis Methods and Tools, more specifically 5A(ii) Statistical Dose-Response Modeling Methods, the HMMH Team suggests the scope to **describe the statistical modeling of doses and responses** and in addition to what is already in the Scoping Document, it should include consideration of survey weights (if any), assessment of impact of noise estimation error on estimated dose-response curves and a section about how the national curve will be estimated.

Missing in Section 5A(ii) is **consideration of dose uncertainty**. Dose observations would be subject to both measurement and model uncertainty. Collecting reliable *measurement* data for determining dose observations would likely be very challenging with UAM aircraft due to their relatively low noise levels and the potential for partial to full ambient masking of flight noise beyond proximity to takeoff and landing locations. Hence, the only quantifiable dose observations uncertainty might be the *model* uncertainty. Ideally, any uncertainty in the

[2] Other aircraft noise models, such as the Advanced Acoustics Model (AAM3) and the legacy NOISEMAP software do not contain aircraft performance modeling. The AAM3 user must input (typically pilot-provided) flight profile information, i.e., altitude, power setting, speed, nacelle angle, roll angle, and angle of attack along each flight track.

dose observations should be accounted for when estimating the dose-response curve, to minimize the potential bias due to ignoring such uncertainty. On the other hand, if the dose uncertainty is not quantifiable at all, then we would acknowledge that the dose-response curve estimated using a model that does not include the dose uncertainty (because it is not quantifiable), would be subject to (not quantifiable) attenuation bias. It should be noted that the NES did not account for uncertainty related to the INM-based dose estimations. Even when model validation exercises have occurred, the quantification of uncertainty for real world application of any noise model can be challenging given the likelihood of models to perform better or worse depending on the characteristics of the area being modeled, the model's capabilities to account for the effects of those characteristics, and the fidelity of model inputs to those characteristics and the true flight parameters of the aircraft being modeled. When conducting model validation work, it may be advisable to identify any conditions in which the model is not expected to perform reliably and avoid selecting survey areas where such conditions would be present.

Regarding Section 5B Survey Methods, the HMMH Team suggests the scope to establish the **basis for the technical survey approach** and considerations for survey and dose test, or "pilot". See Section 5, Tasks 8 and 17 for more detail.

Section 5B(iv) Sampling should have a subitem where the Contractor would describe their proposed **Sampling Methods**, e.g., Address-based sampling (ABS). Some general recommendations are provided in Section 5.

Section 5B(iv)(b) should also include NES-style 'balanced sampling' for **design of the sampling frame** with NASA (and their Contractor team) providing input on the balancing factors to the FAA. Details on this recommendation are provided in Section 5.

In the Scoping Document's Section 6C Community Engagement, NASA may want to add Science, Technology, Engineering and Mathematics (**STEM) engagement** as the X-59 CRT had done.

2.2 Unnecessary Activities

Nearly each of the following paragraphs mentions an activity or consideration in the Scoping Document which the HMMH Team deems unnecessary. The primary idea of each 'extra' is bolded.

We disagree with assuming community tests will include **noise monitoring for the purpose of determining doses** (Section 4B Noise Monitoring). Dose-response relationships will need to be based on long-term exposures of ideally a full year or more. Survey participants would be responding to their long-term exposure, meaning short-term "at the time of survey" measurements would likely not be reliably representative. Long-term measurements at many locations across the country may be infeasible due to the associated costs of equipment purchase/development, deployment, and maintenance. Short-term measurements ahead of the surveys might be conducted for model validation of isolated periods, but ambient contamination is likely to make that challenging at the types of locations where vertiports would most commonly be sited. Even for permanent noise monitoring systems installed around large airports, ambient contamination often makes reliable determination of long-term aircraft noise levels nearly impossible beyond the distances where aircraft noise is the consistently dominant environmental noise source. A small percentage of total events with high level contamination, if not identified and removed, can dominate and artificially inflate the resultant long-term levels calculated from measurements. Beamforming solutions can perform better in isolating the noise sources of interest but would greatly increase costs and complexity and be less practical for deployment at sufficient numbers throughout a community. Noise monitoring would likely be most beneficial for ambient characterization and/or aiding with site selection.

Studying differences across UAM aircraft configurations, as described in Section 5A(i), is unnecessary or a risk/limitation if the FAA will try to do the survey at a point in time when only a couple different UAM aircraft types are being operated. Other new entrants could emerge during the survey or immediately thereafter. At the point when the FAA decides to do the survey, its results will reflect the fleet operating at that time and be caveated as such.

Regarding Section 5B(i) **Study Type**, the HMMH Team thinks the main question here is how to determine the point at which UAM operations become established enough to make the results of the survey sufficiently representative of the population <u>after</u> the study. The question about the long-term applicability of survey results for novel noise sources can probably only be answered by an eventual longitudinal study. A cross-sectional study can later become longitudinal, if repeated in the future with the same participants. The survey results will reflect the people's responses to the state of the UAM environment at the time the FAA chooses to do the study. Regarding NASA's question about how long a survey period is needed for steady-state responses, we will never truly know, and trying to find out would be prohibitively costly.

Although the HMMH Team believes **investigation of Survey Mode** [Section 5B(ii)] is necessary, the effort needed for the investigation can be greatly reduced because of what has been learned. The NES (and its foundational ACRP project) found that Phone surveys resulting in Response Rates as good as mail surveys would be prohibitively costly, if not impossible. Phone surveys should not be considered, unless they are used for follow-ups from the mail survey, ala the NES. Like Phone surveys, in-person surveys where the contractor team would go to the respondents, e.g., knocking on doors, would be too costly compared to a mail survey. Letting the respondents come to the contractor team, like in a mall setting, do not provide a probability sample that can be generalized to the target population.

If the survey were to be done in the next year or so, a self-administered web survey, with possible backup of a paper survey, would be optimal. This is based on the use of an address-based sample that provides an exhaustive listing of the target populations, allows targeting geographical areas subject to the flight paths <u>and</u> provides a means to contact eligible respondents to complete the survey. The web mode provides the highest quality data because it eliminates errors respondents might make on a paper instrument when navigating the questionnaire. A paper supplement might be considered to follow up with non-respondents with a shorter version of the survey asking the key analytical questions, e.g., key annoyance items. This mixed mode approach still provides the best coverage of the general population and the highest response rates. However, the effectiveness of this approach is waning as more of the population gets comfortable responding to web surveys. By the time the survey is launched, e.g., in 2030 or later, the advantages of a shorter questionnaire on paper may not be significant. This would need to be assessed when the survey timeline is finalized.

The first question posed by NASA in Section 5B(iv)(b) assumes an X-59 CRT-like scenario; however, it's unlikely a UAM community test would include **individual event responses**, given the likely frequency of events and the associated burden with responding to each one. Evaluating long-term dose-response, such as YDNL, would not require simultaneous measurements and surveys. If dose measurements are included in the study, they should occur over some period prior to the CRT and be used to aid in calculations of long-term doses in an area.

The answer to the second question posed by NASA in Section 5B(iv)(b) asking if NASA's Varied Advanced air mobility Noise and Geographic Area Response Difference (**VANGARD) study could help guide** where community testing occurs is “maybe”. A VANGARD-style test could be more cost effective than, say, a mail survey to harvest opinions outside of the US for initial comparison to the results of the FAA UAM study. However, a VANGARD-like test in the US, done prior to the execution of the UAM survey, could taint the respondent pool and/or could bias the balanced sampling recommended in Sections 2.1 and 5 of this document. Further, a VANGARD-like study would rely on computer-generated auralizations which are not as accurate as the live sound events.

The HMMH Team believes Section 5B(iv)(c) “Combining Data from Multiple Noise Sources and Communities” is not necessary. The FAA will not want more than one national dose-response curve. The NES dealt with this same issue, e.g., airport-specific curves. We built them and reported them but only did so to demonstrate the airport-specific differences and to build the national curve from them. For purposes of implementing a national noise policy, the FAA wanted a single national curve to be applied across the country, not each state or each airport imposing its own standards. This is the downside to the Community Tolerance Level (CTL) metric as an “alternative” metric to DNL. CTL allows for local/specific annoyance but creates a nightmare for the FAA/federal government to apply noise policy on anything but a nationwide basis. Furthermore, integrating just a single overall UAM dose-response curve with, say, the one from the NES will be sufficiently challenging for the FAA, let alone having UAM-type specific dose-response curves.

The NES went down to 50 decibels (dB) of Day-Night Average Sound Level (DNL). The FAA UAM study would probably be better served by studying similar levels from vertiports and perhaps consider the enroute environment separately. NASA could help by developing the criteria to determine the boundary between the vertiport/enroute environments. HMMH has employed a similar approach in dealing with noise from Unmanned Aerial Systems (UAS) package delivery hubs, where the maximum possible extent at which overflight noise has any influence from takeoff and landing operations is determined as part of the National Environmental Policy Act (NEPA) analysis for siting new hub locations (FAA, 2025; FAA, 2024).

3 Task 2.2.2 - Alternative Approaches

The HMMH Team has no alternative approaches and/or activities to accomplishing the same objectives identified in Section 2 of the Scoping Document. Please see Sections 4 and 5 for our Preferred Approach.

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4 Task 2.2.3 - Preferred Approach

This section identifies the HMMH Team's preferred approach from the intersection of activities associated with Tasks 2.2.1 and 2.2.2 and provides the associated rationale. Section 4.1 discusses the preferred approach at a high level while Section 4.2 discusses several survey method considerations.

4.1 High-Level Characteristics

To facilitate direct comparisons with (or integration with) the NES, the HMMH Team's overall preferred approach for the UAM survey is more NES-like, i.e.:

- A primary survey question asking about long-term cumulative (~12 months) annoyance, vice annoyance from single events, and phrasing the overall annoyance questions with locational context identically to the NES: "*Thinking about the last 12 months or so, while you're at home…*". This would necessitate an annual set of operations data so that Yearly DNL (YDNL) would be satisfied, at a minimum.[3]
- Incentivized respondents to complete the survey process. Incentives have been proven to increase response rates (Mercer et al., 2015) and are elaborated below.
- Masked intent (asking the respondent about several sounds and/or environmental aspects with the UAM annoyance question being put somewhere in the middle of the questionnaire) to minimize bias about UAM activity.
- At least 10,000 respondents.[4]
- Modeling of noise exposure (dose). Although the NES's primary noise metric was YDNL, the UAM study should consider several metrics, including YDNL, and the model should be the one developed/chosen by NASA/FAA best-suited for modeling UAM in the types of environments UAM will typically operate, best-suited for the chosen set of metrics to be analyzed to best correlate with annoyance and one which can be adopted into future versions of FAA Order 1050.1 and be used by the industry for future NEPA-related UAM work.
- Multilevel logistic dose-response modeling. The relationship between the noise exposure level of an aircraft flight event and the probability an individual is highly annoyed by the event is commonly expressed as a logistic regression model, possibly modified to account for the specific setting of the study. Simple logistic regression models do not account for any differences between individuals in how they perceive the aircraft noise. If any such differences exist, one should include model covariates, as available and relevant, and/or an individual-level random effect in the simple logistic regression. The multilevel logistic dose-response model comprises the simple logistic regression level and the individual-level random effects level.

[3] This responds to NASA's questions in the Scoping Document's Sections 4A(ii)(c) and 5B(i).
[4] This responds to NASA's question in the Scoping Document's Section 5B(iv)(a).

Like the X-59 CRT, we recommend the FAA structure the UAM survey to have two stages: (1) a Planning Stage where/when the dose estimation method and survey(s) are fully planned and prepped, and (2) an Execution Stage where/when the surveys are conducted, data is analyzed, and results are published. The Planning Stage is where NASA's tech challenge project would fit.

The HMMH Team believes the overall level of effort and complexity of the UAM community response survey is greater than that of the NES, even when accounting for the items from the scoping document our preferred approach does not include. This is likely to be a larger effort than the NES in planning because of the various enabling activities that need to occur prior to the test, and in execution/analysis of the survey given the need to evaluate UAM noise in and out of the context of legacy aviation and other new entrants such as sUAS, and the challenges related to capturing a nationally representative samples of survey respondents and UAM vehicle designs.

4.2 Survey Method Considerations

There are several considerations when determining the preferred survey methods for the study. An initial consideration is when to conduct the survey and noise assessments. As mentioned in Section 1, we understand NASA envisions the CRT to start in 2030 "when certificated UAM vehicles are flying commercial operations over populations for extended periods of time." However, other qualifications, such as the number of areas in which UAM aircraft have begun operating, need to be considered. The adoption of UAM vehicles is likely to unfold over time making the definition of a 'national sample' somewhat of a moving target. Table 4-1 lists initial advantages and disadvantages of two approaches to starting the surveying. Executing surveys in either approach would lag the start of UAM operations in those areas by a year or more. Our Preferred Approach is B Survey Mature System because of the advantages listed in the middle column.

Table 4-1. Two Approaches to Starting the Survey

Approach	Advantages	Disadvantages
A. SURVEY EARLY ADOPTERS. Start the surveys when there are 1-2 areas (not necessarily geographically separated) having adopted UAM; survey new areas at least 1 year from when they come online.	1. Data can be collected at the earliest time possible and early analyses can inform noise policy about UAM annoyance 2. Allows lessons learned to improve subsequent survey locations 3. Easier if deployment of any equipment to survey locations is involved (noise monitors, ADS-B recorders, etc.), as such deployments could be staggered requiring less equipment.	1. Spreads the data collection over a longer period; likely more costly overall 2. Responses to UAM noise when they are relatively new may be quite different than when residents acclimate to them over multi-year periods.

Approach	Advantages	Disadvantages
B. SURVEY MATURE SYSTEM. Survey when there are many[5] UAM locations operating across the country	1. Compresses the data collection over a shorter period; likely less costly overall 2. Sample frame of UAM locations will be relatively complete and a national sample can be drawn 3. Gives the population affected by UAM noise some time to form an opinion 4. More time for source data collection and tool advancement to improve capabilities for dose estimation.	1. Delays informing noise policy about UAM annoyance 2. May require greater amounts of equipment to be acquired for simultaneous deployment.

A second consideration is the extent to which the study will compare annoyance levels for residents who are and are not subject to UAM aircraft flight patterns. A single cross-sectional survey of those living along UAM aircraft flight paths will provide data to measure levels of annoyance and develop a dose response curve. However, this does not provide an evaluation of how the exposed population's overall annoyance compares to those not subject to it. There are several ways to address this:

1. Do a longitudinal survey, i.e., survey the same residents at two points in time, that measures annoyance levels before and after UAM aircraft are fully operational. While feasible, this would be (a) expensive, (b) it would not likely result in an adequate response rate, and (c) would not account for the mobility of residents moving in and out of the area between survey contacts.
2. Repeated cross-sectional surveys, one done before and another after the aircraft have become fully operational for sufficient time. This design is less expensive to implement, but more importantly, would measure the overall annoyance levels of all residents, not just those who participated in the first wave of the panel.
3. Conduct a cross-sectional survey once enough UAM aircraft are operational – this is the HMMH Team's preferred approach. A sample would be drawn among residents who are proximate to the flight paths of the aircraft. A second sample would consist of individuals who live in areas that are not proximate to the flight paths but experience similar ambient noise, i.e., the "control" group/area. The two areas could be matched with important demographic characteristics, e.g., income, race, age. The assessment would compare the annoyance levels between the two areas. This approach can be completed in less calendar time than the two above approaches and provides a basis for evaluating the relationship of ambient noise to reported annoyance.

Another consideration is the mode of the survey. Unlike the NES's mail survey as the primary mode, we prefer the primary survey mode to be a longer web-based survey and a mailed one-page paper survey as backup for initial non-responses—a mixed-mode web/paper survey. The following paragraphs provide our rationale for our preferred survey mode.

[5] Criteria would need to be established.

It is expected that the survey will refer to annoyance over a fixed period, e.g., last 12 months. To target the sample proximate to the flight paths of the aircraft, an ABS will be used to select respondents. Using the address, it is possible to contact households by postal mail, either asking them to go to a website to complete the survey and/or to fill out a paper survey included in the packet. The NES used a short paper survey and strategically sampled areas around airports to measure annoyance. Our initial recommendation is to use a web survey for two reasons:

1. We anticipate the questionnaire to be considerably longer and more complicated than the paper NES survey. The web can accommodate complex skip patterns without jeopardizing data quality.
2. Less Cost. A web survey is less expensive than a paper survey. A paper survey adds postage and printing costs, especially if there are multiple follow-ups to non-respondents.

A mixed-mode web/paper survey is likely to maximize response rates. In 2025, the use of both modes in conjunction with an ABS design maximizes response rates (Coffey, et al., 2024). One compromise would be to send the initial requests as a web survey. After two or three mailings, we would ask a sub-sample of non-respondents to complete a shorter (one page) paper survey to collect the most critical items. This provides a way to expand the overall response to the survey and a way to assess possible non-response bias of the survey. Of course, the environment for doing surveys is changing rapidly and it is difficult to predict which methods will be most effective when the proposed survey is launched, which we would expect to be no earlier than 2030. A web/paper survey may not be optimal at that time. It may be the case that a single mode, web survey, would be best or one that is supplemented by emerging methods, e.g., text message or interactive voice response. For the purposes of this document, the HMMH Team chooses the mixed-mode web/paper survey as part of its preferred approach.

The survey should be completed by an adult in the household that is selected using a prescribed, preferably random, process. With a web survey, it is possible to use a probability-based method such as the Rizzo-Brick-Park selection method (Rizzo et al., 2004). This is a nonobtrusive method to randomly select a respondent. To maximize the response rate, small monetary incentives should be used at different points of the survey process. The initial letter to the household should include a token incentive to get the household adult’s attention. The incentive should be visible with a window on the envelope to display part of the money (DeBell et al., 2020). This technique minimizes the number of letters that are never opened. The household member selected to participate in the study should be promised a nominal incentive to complete the questionnaire, e.g., $15. The incentive can be delivered using an electronic code sent when the survey is finished.

The questionnaire should include items on annoyance with the general environment, as well as questions that target UAM operations. To the extent possible, it would be useful to embed the general annoyance questions within other/similar questions on other possible disturbances in the area, as was done on the NES. This minimizes respondent understanding the purpose of the survey and reduces the extent they will choose to respond because of attention to UAM operations (avidity bias). This is particularly true in a paper survey but maybe less necessary in a web survey where the questions cannot be viewed in advance. The questions on annoyance should be taken from current International Commission on the Biological Effects of Noise (ICBEN) guidelines (Fields et al., 2001). Later questions can focus more specifically on the UAM operations, as well as a measure of the individual’s tolerance for different types of environmental noise. We also recommend that questions on the use of and overall viewpoints of UAM aircraft, e.g., considering everything, does the respondent view them as a positive addition to society, are included to understand factors that may influence and/or counterbalance expressed annoyance.

5 Task 2.2.4 - Description of Preferred Approach Activities

For the preferred approach in Task 2.2.3 (Section 4), this section provides detailed descriptions of activities down to the lowest level practical including an assessment of the level of maturity (Section 5.1) and identification of technical risks for each (Section 5.2).

5.1 Activity Description

The HMMH Team envisions the Planning Stage to have the following 18 deliverables/activities/steps.

1) Project Plan (unless FAA/NASA's CDRLs provide its surrogate). The Project Plan will likely be an update to this report, informed by what is learned during the contracting process.

2) Management Plan, which describes how the awarded Team will manage the project.

3) Identify POCs for agency and international coordination per Scoping Document item 6A. Suggest an Expert Panel be devised. The awarded Team will collaborate with NASA and FAA to form and contact an Expert Panel.

4) Sites and Routes Evaluation Report. This report will identify/analyze potential vertiports, routes, and possible respondents to be surveyed (sampling frame) to see if they provide sufficient sampling, national representativeness, etc., given criteria provided by FAA/NASA.

5) Select and Validate Dose Estimating Tool. Regarding Tools [Section 4A(i) of the Scoping Document], the HMMH Team suggests NASA's development of needed analytical tools be limited to evaluating and modifying existing Off-the-Shelf (OTS) tools and that this "development' occur early in the Planning Stage. FAA's selection of publicly available tools and best practices should be occurring now to prepare for future UAM NEPA, just as approaches have already been developed for the FAA's small UAS (sUAS) NEPA-related work.[6] As a competing simulation model to Version 3.2 of the Advanced Acoustic Model (AAM3), SoundPLAN™ should also be considered. However, the HMMH Team recognizes FAA or NASA will not likely adopt a tool they do not fully control or a tool where they lack access to its source code. Rather, they will likely settle on federally owned/controlled models or development of new ones by NASA or FAA. To avoid potential bias in the ultimate regulatory process, the model chosen for the UAM study should be the same as what the FAA would eventually allow in FAA Order 1050.1, advancing that model's capabilities to sufficiently fill both roles. Regardless, the tool selection task would weigh the advantages and disadvantages of candidate models and recommend one to carry forward to the UAM CRT.

One important aspect of tool selection is whether the tool will require OEM or pilot inputs/data, e.g., if AAM3 is chosen, AAM3 will require the user to input flight profile data, i.e., altitude, power setting, speed, roll angle,

[6] Regarding 4A(i)(a) Readiness of Modeling Approaches, by the time this UAM study would occur, there will likely be data sources available to quantify the amount of sUAS activity in an area. The availability of such data is likely to come out as a requirement of the Part 135 and Part 108 UAS work HMMH is doing for the FAA. Evaluation of sUAS noise for environmental reviews is currently done as a non-standard process without any "noise model" software. The existing process used for NEPA analysis, however, would not allow for accurate determination of sUAS noise doses in an area. Further tool development work would be required to enable determination of sUAS noise dose within a survey area.

angle of attack, nacelle angle, etc. All but altitude and speed will need to be harvested from the OEM or a pilot of the vehicle.

Tool validation, comparing measured and predicted doses, should occur in the Planning Stage. Keep in mind that the NES studied aircraft DNL down to 50 dB, which could have been at or below the ambient DNL of some of the communities it studied. Being able to predict the UAM's noise exposure down to levels comparable to or less than the local ambient will be an important tool development goal.

6) Ambient Characterization (if necessary). If the chosen noise metric is dependent on the ambient sound level, e.g., audibility, one of the enabling activities for Tool Validation (see above) is what is mentioned in Scoping Document's Section 4A(iii) Ambient Characterization, i.e., to assess the suitability of ambient noise models, and potential investigation into the variability of the ambient noise level over time. However, one important factor will be to decide what to include in the ambient noise environment, e.g., should all non-UAM sound constitute the ambient sound level, including the sound from all legacy and sUAS aviation vehicles?

Ambient noise levels can provide context to the surveyed annoyance, and they can perhaps be used to correlate to the surveyed annoyance. The recommended method for doing either of these is to ask respondents about sounds in their environment other than UAM sound. Additionally, as mentioned in Section 4.2, including areas not subject to UAM noise in the survey provides a way to evaluate the effect of ambient noise on overall annoyance.

7) Dose Estimation Report. This report will identify how dose will be quantified, i.e., how the modeling will be done. It will describe how numbers of flight operations, period of day (if applicable), flight tracks/routes and flight profiles (altitude, power, operating state) are determined for purposes of modeling. The report will also describe the modeling for the future Survey and Dose Estimation Test (see #17).

8) Survey Methods Report. The report will establish the basis for the technical survey approach and will include a description of a future Survey and Dose Estimation Test (see #17). Sections should include:

a) Sample size determination,
b) Selection of respondents and recruitment goals,
c) Recruitment plan,
d) Roles and responsibilities,
e) Institutional Review Board (IRB) considerations, and
f) Office of Management and Budget (OMB) considerations/planning.

Once the questionnaire is developed, a "survey test", or "pilot", should be implemented that administers the survey procedures. A pilot test is essential for two reasons. One is to run through the study protocols to make sure they are working as intended. It is prudent to catch any errors in procedures or programming at this stage, rather than the main study. For example, while the web survey will be exhaustively tested, a pilot will be a final last check to make sure the survey program works as intended. Second, the pilot provides a way to 'level-set' expectations on what the response rate will be. While the HMMH Team will plan around projected rates, each study poses unique circumstances, and it is best to have a good idea of what to expect when going into the field for the actual study. The pilot may suggest other ways to maximize the rate.

The sample for the pilot test should consider areas where drones are being used. The widespread use of package delivery drones is anticipated to precede that of UAM aircraft but has similar characteristics. Both will be sited throughout metro areas on commercially zoned land with flight activity dispersing out from the respective operation hubs. The relevant area of noise exposure will likely be limited to the immediate vicinity of the hub/vertiport, as they may be generally undetectable during enroute flight (at least for those indoors and likely much of the time for those outdoors). Both are novel aviation noise sources to which people will not initially be accustomed to hearing. Sampling areas for the pilot that are close to the hubs and those away from the hubs can simulate the use of an exposed and a 'control' area. Finally, the final survey will likely contain questions about drone noise, as they will likely be part of the overall aviation activity in areas with UAM flights. The pilot will be an opportunity to test these questions.

To estimate a nationally representative UAM dose-response curve, quantifying the relationship between UAM noise exposure and community annoyance, the survey should collect information from a statistically representative number of adult residents living around a balanced sample of vertiport-to-airport paths, available at multiple locations across the nation and objectively chosen to reflect the nation as a whole. With a limited number of vertiport-to-airport paths, one would only be able to attempt estimating a dose-response curve representative of the specific paths and, likely, all such paths would be selected in the sample. Moreover, the adult population living around the sampled paths may have limited variability in demographic and other community characteristics and the area around a vertiport where noise may be audible might be limited, narrowing even further the definition of 'national representativeness.' Finally, considerations might be needed if the scope of the work would include the evaluation of community response to more than just UAM noise, e.g., ambient noise and aviation noise such as legacy aviation and drones.

The sampling frame for the study would consist of vertiport-to-airport paths following specific eligibility criteria, such as the minimum number of average daily operations and a minimum number of adults exposed to noise at target sound levels. If a very limited number of vertiport-to-airport paths would be available nationwide, then the frame would consist of all these paths, irrespective of their characteristics. Paths likely to be included in future UAM operations may also be considered (NASA, 2025b). The rest of the discussion assumes a sizeable list of vertiport-to-airport paths available from which to sample.

Although probability samples are the "gold standard", with small samples they may not perform as desired.[7] Stratification is intended to balance the sample on stratification factors, but, because only a limited number of strata can be formed, the resulting sample may still appear unrepresentative with respect to characteristics not used in the stratification. For example, the sample may exclude vertiports from a particular region, if region is not used as a stratification variable.

The national vertiport-to-airport sample is expected to be small. Hence, one might want to use balanced sampling, a method for using the known information about the population in the fullest possible way when selecting a sample. With this sampling procedure, the aim will be to match the sample proportions to the corresponding population proportions, on different balancing factors, like the NES did with factors such as high/medium/low number of average daily operations, high/low population within twenty miles of the airport, and groups of temperature ranges. Noise exposure factors determined from laboratory testing should also be considered, such as UAM noise sources, different radii from vertiports and under enroute segments, areas with different pre-existing noise conditions, background noise levels, time of day, and land use (NASA, 2025b).

[7] As an analogy, if you flip a fair coin 1000 times -large sample-, you expect to see roughly half heads and half tails; but if you flip the coin twice -small sample-, it would not be surprising if it came up heads both times

Because the sample is balanced on desired characteristics in this design, it is representative of the population of vertiport-to-airport paths. Therefore, each vertiport-to-airport path in the sample would count equally toward computing the national dose-response curve, avoiding discussion of why some vertiport-to-airport paths in the sample would "count" more than others. In addition, sampling weights would not need to be calibrated (adjusted to agree with population values for known population quantities) and it would not need to be used in the analysis of the data, such as hierarchical modeling for estimating dose-response curve (Lohr, 2001).

Like the NES's stratifications, the target population for each vertiport-to-airport path would be defined as addresses in bands of UAM noise level. The number of vertiport-to-airport paths and the sample size for each vertiport-to-airport path would be selected to allow accurate estimation of the national dose-response curve. To achieve high precision for the estimated dose-response curve, a stratified random sampling design could be used to select addresses across a range of noise exposures. Addresses would be selected from a household sampling frame such as the US Postal Service Computerized Delivery Sequence File, possibly strata information such as GIS shape files and eligibility information such as non-businesses. Such design would allow the sample to have greater sampling fractions for addresses at greater noise exposures than would be possible with simple random sampling within vertiport-to-airport paths. Target sample sizes could be inflated to allow for a reserve sample if response rates were less than expected, or that the rates for vacant and seasonal housing or undeliverable addresses would be greater than expected.

The pilot would also include dose estimation (modeling) per the plan delivered as part of Task 7 to ensure all works as planned.

9) Survey Instrument. The questionnaire should draw from ICBEN items endorsed to measure annoyance. To obtain information on contextual effects, additional questions should be included to collect:

a) Differences in annoyance generally, e.g., over the past year, versus annoyance at specific times of day (day vs. night).
b) Whether the respondent uses UAM and therefore may benefit from them.
c) Whether the respondent feels UAM generally provides a benefit to society, whether personally used or not.
d) Whether the respondent has any fears about UAM, e.g., crash potential, or non-acoustic annoyance factors, e.g., annoyance from visual aspects.
e) Additional items to understand the factors driving annoyance, e.g., interrupting activities, sleep, vibration, rattle, etc.
f) Duration of residence to quantify time exposed to UAM at their home.
g) Demographic information and characteristics of the residence.

While there may be several other data points that are of interest to the sponsor, the survey should be no more than 20-25 minutes in duration to maximize response rates and optimize OMB approval.

10) Survey Analysis Plan. This plan addresses how the survey responses will be analyzed and curve-fit, including consideration of dose uncertainty (if quantifiable). We recommend hierarchical Bayes models for the estimation of the UAM dose-response curve that accounts for uncertainty in dose observations. This recommendation is based on preliminary research. It was observed that the estimated dose-response curves appear sensitive to uncertainty in dose observations, being subject to attenuation bias. In addition, it was demonstrated that hierarchical Bayes models successfully capture the complex structure of the dose data, borrowing strength across participants, accounting for the uncertainty in dose observations, and satisfying known relationships between alternative dose observations, when needed. Sensitivity analysis and model validation should be part of the model development, ensuring valid and robust inference. As stated in Section 2.1, if the dose uncertainty is not quantifiable at all, then we would acknowledge that the dose-response curve estimated using a model that does not include the dose uncertainty (because it is not quantifiable), would be subject to (not quantifiable) attenuation bias.

The analysis plan will demonstrate how the various survey variables will be employed to better understand annoyance and the drivers of annoyance. It will also include details on how non-survey data will be used to enhance the analysis, in addition to dose, this could include geographic information for the respondent, characteristics of UAM operations near the respondent's home, background noise levels, etc. Information from the comparison of annoyance levels between the sampled noise and control areas will be included, too.

11) Obtain review of Expert Panel/Coordinating Agency. FAA/NASA would request the Expert Panel devised in Step #3 to review the work products as approved by FAA/NASA, i.e., items 4 through 10, and provide written comments. Their review would not be done all at once. Expert Panel review would need to occur after FAA/NASA review of each deliverable, after the contract team revises its draft work.

12) Finalize deliverables to-date that were reviewed by Coordinating Agencies, which are anticipated to be the deliverables described in Tasks 4 through 10 above.

13) Generate Institutional Review Board (IRB) Application and Approval Letter and Submit. The IRB reviews research involving human subjects to ensure ethical, safe, and equitable treatment of the subjects. The IRB Application Package will be developed by the Contractor Team and submitted to its IRB. The Application will include:

a) Study overview
b) Informed Consent process
c) Risks/benefits
d) Data confidentiality/security/destruction
e) Survey instruments and all communications materials involved with recruitment of survey participants, as appendices.

Westat has an in-house IRB which could be satisfactory for the Survey and Dose Test.

14) Generate and Submit OMB Paperwork Reduction Act Clearance Application Package. The OMB Application requesting a Paperwork Reduction Act Clearance is required for any federal government survey conducted on 10 or more members of the public. The OMB Application Package would be submitted by FAA. In support of this submission, the HMMH Team would provide:

a) All communications materials involved with recruitment of survey participants, including approval from FAA Public Affairs Office of language and use of FAA/DOT logo
b) The final survey questionnaire, including screenshots if the survey will be delivered electronically
c) A supporting statement for OMB Form 83-I, including both Sections A and B.

15) Noise Exposure Estimation and Matching Report. This deliverable is the key set of documents describing and demonstrating the procedure for estimating the UAM sound levels experienced by participants in the eventual Community Tests (CTs).

16) Community Test Report Template. This document provides a consistent set of information and reporting format for results of each CT. The template shall be organized into appropriate sections (for summary and full data) to allow populating of at a minimum, the following information:

a) Description of the vertiport or route and test locations
b) Descriptions of flights, including aircraft trajectories and aircraft state information
c) Survey information
d) Acoustic information
e) Cumulative survey data matched with noise exposure data
f) Forward Planning

17) Conduct Survey and Dose Estimation Test and Submit Report. The deliverable will include survey results from the test and will also resemble the NES's chapter/appendices on modeling, i.e., include noise modeling data collection, analysis and results. In addition to a report, the deliverable would include a data collection and processing package, which would include all data, scripts, and output files.

18) Community Test Planning Report. This report provides documentation of the entire planning effort in support of the Execution Stage. It should provide an overall summary of all activities and results of the Planning Stage. This report should be a document for internal use by the FAA and its partners (government or contractor) and is not intended for public release. Therefore, external reviews or development of "layman-type" language for public versions of the report are not required.

5.2 Risk Identification

We assigned a risk score using NASA's risk scoring methodology. Table 5-1 lists the risks and a risk statement. We judged the likelihood and consequence of the risk statement on a scale between 1 and 5, with 1 being least likely/minimal consequence and 5 being most likely/maximum consequence. With those two ratings, we entered Table 5-2 and obtained the risk score, which is colored green for scores between 1 and 10 and is considered low risk, yellow for 11-20, considered medium risk, and red for 21+, being considered high risk. Except for Task 5, none of the 18 tasks have high technical risk (red shading). Most tasks have medium technical risk (yellow shading). For Task ID 5, we identified two risk statements, one yielding low risk and the second (selected tool requires unavailable pilot/OEM inputs) yielding high risk.

Table 5-1. Technical Risks

Task ID	Technical Risk Title	Technical Risk Statement	Likelihood	Consequence	Risk Score and Color
1	Project Plan	n/a (administrative deliverable)	1	1	1
2	Management Plan	n/a (administrative deliverable)	1	1	1
3	Expert Panel/Coordinating Agency	An advisory/review panel is not approved by FAA/NASA.	3	4	19
4	Sites and Routes Evaluation Report	The report will identify no or too few vertiports and routes or that national representativeness goals will not be achieved or sample size will not likely be achieved.	2	3	11
5	Select Dose Estimating Tool	FAA or NASA adopts a tool they do not fully control or a tool where they lack access to its source code.	1	3	5
5	Select Dose Estimating Tool	The selected tool requires OEM or pilot input, e.g., flight profile data, which is not available.	3	5	21
6	Ambient Characterization (if necessary)	FAA or NASA requires ambient characterization.	3	4	19
7	Dose Estimation Report	The report does not adequately describe how dose will be estimated for the Survey and Dose Test and for the Execution Stage.	2	5	17
8	Survey Methods Report	The report does not adequately describe the survey methods for the Survey and Dose Test and for the Execution Stage.	1	5	12
9	Survey Instrument	The instrument fails to address the goals of the project.	1	5	12
10	Survey Analysis Plan	The report does not adequately describe the survey analysis methods for the Survey and Dose Test and for the Execution Stage.	1	5	12
11	Review of Expert Panel/Coordinating Agency	The Panel concludes with fatal flaws in the work products to-date.	1	4	8
12	Finalize deliverables from Tasks 4 through 10	n/a (administrative deliverable)	1	1	1
13	Generate IRB Application and Approval Letter and Submit	The IRB does not approve the project.	1	5	12
14	Generate and Submit OMB Application Package	The instrument generates more burden than the X-59 CRT's or NES's survey instrument.	3	3	15
15	Noise Exposure Estimation and Matching Report	The report does not adequately address how surveys will be matched to doses.	1	3	5
16	Community Test Report Template	The report is not sufficiently comprehensive to address the results for a given vertiport/route.	2	1	2

Task ID	Technical Risk Title	Technical Risk Statement	Likelihood	Consequence	Risk Score and Color
17	Conduct Survey and Dose Estimation Test and Submit Report	The Survey and Dose Test results in significant changes to the survey design and/or dose estimation techniques.	1	4	8
18	Community Test Planning Report	n/a (administrative deliverable)	1	1	1

Table 5-2. NASA Risk Scoring Assignment

Likelihood	Risk Score				
5	10	16	20	23	25
4	7	13	18	22	24
3	4	9	15	19	21
2	2	6	11	14	17
1	1	3	5	8	12
Consequence:	**1**	**2**	**3**	**4**	**5**

6 Task 2.2.5 - Milestones and Key Decision Points

From the Preferred Approach (Section 5), Table 6-1 identifies significant milestones and any key decision points (KDPs), each with a brief description, due date, and exit criteria, assuming a 3-year total duration[8] from start to finish. This timeframe would allow the test preparation work to be completed prior to the test(s) being executed. Due dates are listed relative to the written Notice to Proceed (NTP) from the government. Formation of the Expert Panel/Coordinating Agency and its review of the set of deliverables are important milestones and/or key decision points (KDP) for the FAA/NASA. Another KDP for FAA/NASA is the Ambient Characterization because the dose estimation methodology will depend on it. Although this KDP is listed with a due date of "NTP + 3 months" in the table, it should ultimately be done prior to contract award. The final KDP is the results of the Survey and Dose Test; approval of that report serves to "green light" the ensuing Execution Stage.

Table 6-1. Milestones and Key Decision Points

Task ID	Task/Deliverable/Activity	Mile-stone?	Key Decision Point?	Due Date	Exit Criteria
3	Expert Panel/Coordinating Agency	YES	no	NTP + 3 months	Panel is formed and notified
6	Ambient Characterization	no	YES	NTP + 3 months	FAA/NASA selects metric(s) and makes decision about the need for characterizing the ambient
5	Select and Validate Dose Estimating Tool	YES	no	NTP + 12 months	Tool selected and validated with FAA/NASA criteria
11	Review by Expert Panel/Coordinating Agency	YES	YES	NTP + 19 months	Panel completes their review of materials and provides comments
13	IRB Approval	YES	no	NTP + 20 months	IRB provides approval
14	OMB Approval	YES	no	NTP + 2 years	OMB provides approval
17	Conduct Survey and Dose Estimation Test & Report	YES	YES	NTP + 3 years, 2 months	Report approved
18	Community Test Planning Report	YES	no	NTP + 3 years, 4 months	Report approved; project completed

[8] The HMMH Team's timeline resulted in a duration of 3 years and 4 months, which is consistent with development of a *notional* Gantt chart.

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7 Task 2.2.6 - Notional Gannt Chart

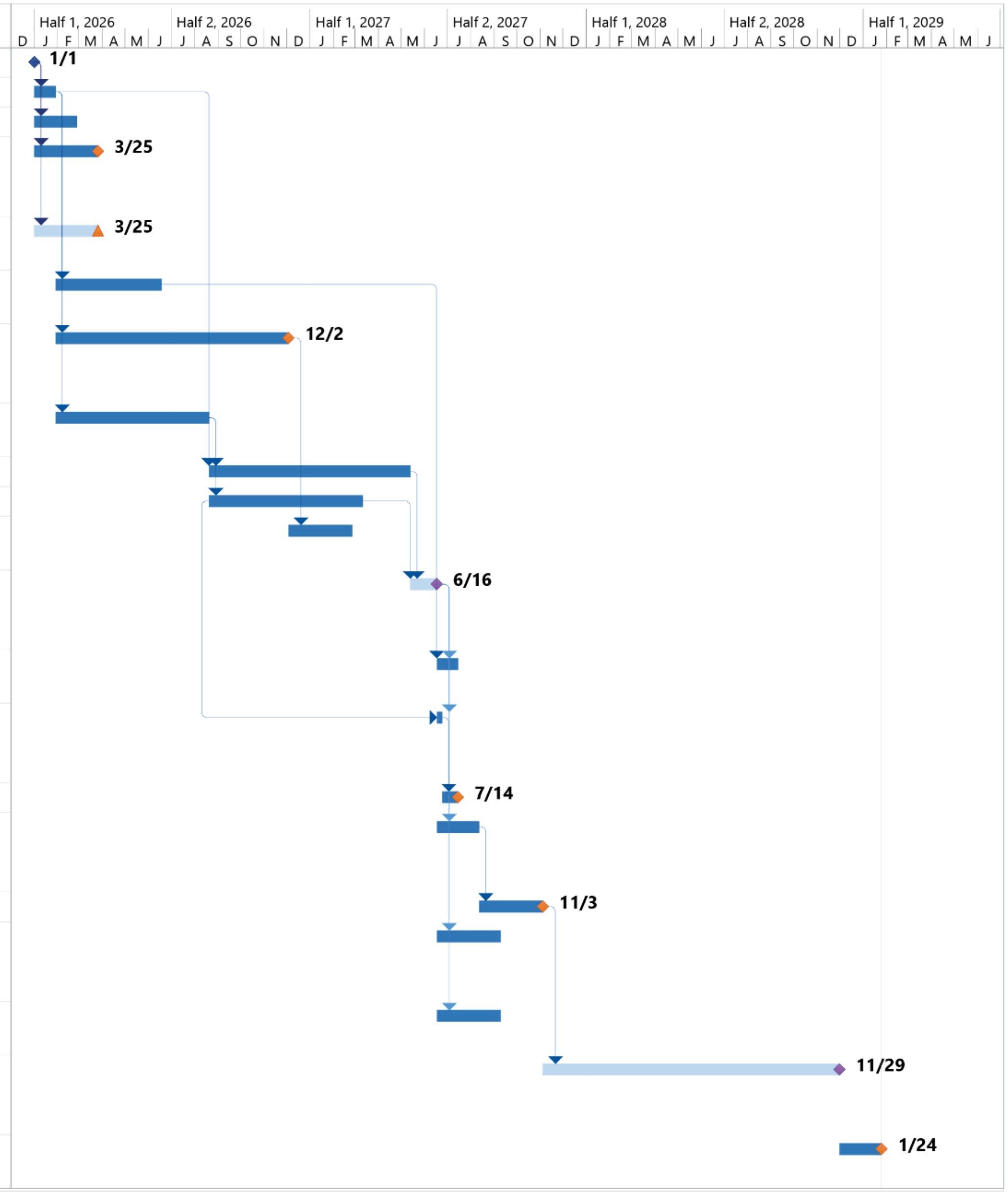
Printed from MS Project file "HMMH_UAM_gantt.mpp" which is based on Sections 5 and 6, Figure 7-1 provides a notional Gannt chart showing key milestones and KDPs, tasks, start and end dates, and dependencies. For brevity, we assumed Notice to Proceed (NTP) date of January 1, 2026. Milestones are shown as orange diamonds. KDPs are shown as orange triangles. Milestones which are also KDPs are shown as purple diamonds.

To expedite the Planning Stage and keep it within an approximate 3-year duration, some tasks will need to be conducted in parallel throughout the life of the project. Start-up activities such as the Project Plan and Management Plan will be developed while early technical tasks such as Sites and Routes Evaluation and Survey Methods reports are being generated. The Survey Instrument and Survey Analysis Plan will be developed concurrently.

In terms of dependencies, the Survey Analysis Plan cannot begin in earnest until (at least the draft) Survey Methods report is completed. The OMB process must follow the IRB process, which, in turn, must wait until the Expert Panel/Coordinating Agency reviews the Survey Analysis Plan. The Survey and Dose Test cannot begin until OMB approval is obtained, but preparatory activities such as the Noise Exposure Estimation and Matching Report and Community Test Report Template can occur while OMB is reviewing the Package.

Figure 7-1. Notional Gannt Chart from the HMMH Team

ID	Task Name	Duration	Start	Finish
1	NTP	0 days	Thu 1/1/26	Thu 1/1/26
2	Project Plan	1 mon	Thu 1/1/26	Wed 1/28/26
3	Management Plan	2 mons	Thu 1/1/26	Wed 2/25/26
4	Expert Panel/Coordinating Agency	3 mons	Thu 1/1/26	Wed 3/25/26
5	Ambient Characterization	3 mons	Thu 1/1/26	Wed 3/25/26
6	Sites and Routes Evaluation Report	5 mons	Thu 1/29/26	Wed 6/17/26
7	Select and Validate Dose Estimating Tool	11 mons	Thu 1/29/26	Wed 12/2/26
8	Survey Methods Report	29 wks	Thu 1/29/26	Wed 8/19/26
9	Survey Instrument	38 wks	Thu 8/20/26	Wed 5/12/27
10	Survey Analysis Plan	29 wks	Thu 8/20/26	Wed 3/10/27
11	Dose Estimation Report	3 mons	Thu 12/3/26	Wed 2/24/27
12	Review by Expert Panel/Coordinating Agency	5 wks	Thu 5/13/27	Wed 6/16/27
13	Finalize Deliverables	1 mon	Thu 6/17/27	Wed 7/14/27
14	Deliver and Submit IRB Application and Approval Letter	1 wk	Thu 6/17/27	Wed 6/23/27
15	IRB Approval	3 wks?	Thu 6/24/27	Wed 7/14/27
16	Generate & Submit OMB Application Package	8 wks	Thu 6/17/27	Wed 8/11/27
17	OMB Approval	12 wks?	Thu 8/12/27	Wed 11/3/27
18	Noise Exposure Estimation and Matching Report	3 mons	Thu 6/17/27	Wed 9/8/27
19	Community Test Report Template	3 mons	Thu 6/17/27	Wed 9/8/27
20	**Conduct Survey and Dose Estimation Test & Report**	**280 days**	**Thu 11/4/27**	**Wed 11/29/28**
24	Community Test Planning Report	2 mons	Thu 11/30/28	Wed 1/24/29



8 General Comments about the Scoping Document

Although not required, HMMH offers the following comments about the scoping document itself, assuming some of it moves forward to contracting.

1. The document should also mention FAA's ongoing National Sleep Study (NSS), along with the NES and X-59 CRT as relevant projects related to the contemplated UAM dose-response study.
2. NASA's secondary objective (Section 2 of the Scoping Document) omitted the consideration of airspace with legacy aviation in addition to UAM and sUAS, such as is likely to be the case in the vicinity of any airports. Does the dose-response relationship around airports change once UAM and sUAS are added to the mix, even if they may result in only changes to cumulative noise metrics like YDNL? FAA's primary concern will likely be public use airports, since those are the facilities subject to the noise studies required under NEPA and Part 150, which evaluate aviation noise according to the established regulatory criteria. As vertiports will primarily be private facilities, they may not be subject to such reviews at the federal level.
3. Section 4C(i)(b) alludes to but does not specifically mention the Number of Events (at or) Above a Sound Level Threshold (NA) metric. Given its fame, we suggest NA be mentioned.
4. The definitions for "alternative metric" and "supplemental metric" in Section 4C(ii)(a) should be clarified.
5. The HMMH Team suggests NASA's RFP include a list of requirements for the study and a list of potentially optional tasks, e.g., diving into "alternative" metrics as mentioned in Section 4C(ii)(a). Incorporating "alternative" metrics would likely require a lot of effort during test/survey design and would likely fall into the 'optional' category.

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9 References

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