# Remotely Administered Psychoacoustic Test for sUAS Noise to Gauge Feasibility of Remote UAM Noise Study

**Siddhartha Krishnamurthy*, Stephen Rizzi*, Ryan Biziorek†, Joseph Czech‡, Jeffrey Berg†, Dillon Tannler‡, Devin Bean†, Arman Ayrapetyan†, Andrew Nguyen†, Jonathan Wivagg+**

*NASA Langley Research Center, †Arup, ‡Harris Miller Miller & Hanson, Inc., +Westat

## Abstract

The National Aeronautics and Space Administration (NASA) remotely administered a psychoacoustic test in fall of 2022 as the first of two phases of a cooperative Urban Air Mobility (UAM) vehicle noise human response study. This first phase, described here, was a Feasibility Test to compare human subject responses with a previous in-person psychoacoustic test that found an annoyance response difference between small Uncrewed Aerial System (sUAS) noise and ground vehicle noise. This paper discusses the Feasibility Test online layout, sound calibration method, software development, stimuli selection, test subject recruitment, and test administration. Test performance is measured through comparison of annoyance response data with the previous in-person test. The test also investigated whether a contextual cue to test subjects influenced their annoyance response. Response differences between test subjects in geographically distinct areas are analyzed. Administrative challenges that were encountered during the test are discussed, and improvements to administering subsequent remote tests are recommended.

## 1. Introduction

### *1.1. UAM Vehicle Noise Human Response Study*

The National Aeronautics and Space Administration (NASA) seeks to remove barriers to the operation of Urban Air Mobility (UAM) vehicles [1]. UAM vehicles are a part of NASA's vision for Advanced Air Mobility, which seeks to develop new air transportation systems that move people and cargo between places previously not served or underserved by aviation [2]. Representative UAM vehicle concepts involve the use of electrically driven rotors, and the noise from these air vehicles in communities may restrict their operation.

To address this noise concern, NASA has been pursuing research to better understand the human response to UAM vehicle noise. This includes the formation of the UAM Noise Working Group (UNWG), with members from academia, industry, and government, to identify and address UAM noise issues. The UNWG published a white paper identifying noise barriers to UAM, including the need to perform laboratory studies to understand the perception of UAM vehicle noise and understand geographical variations in perception [3].

Based on these recommendations, members of the UNWG proposed a cooperative psychoacoustic test using facilities spanning multiple geographic locations to obtain data on community variation in response. Goals of the cooperative study, which is called the UAM vehicle noise human response study, are:

1. Assemble a wide range of UAM vehicle sounds through cooperation between multiple agencies and organizations for use in human response studies.
2. Conduct psychoacoustic tests using the database of UAM vehicle sounds to provide insights into human response to UAM vehicle noise that would be challenging, in terms of access to stimuli and a wide geographic demographic, for any single agency or organization to acquire.
3. Assemble the stimuli and annoyance responses into a database that can be used by members of the UAM community for subsequent analyses.

The UAM vehicle noise human response study is divided into a feasibility phase and an implementation phase. This paper details results from the feasibility phase psychoacoustic test, which will be referred to as the Feasibility Test. The novel coronavirus outbreak highlighted the potential utility of a remote (web-based) psychoacoustic test platform for human response studies. Section 2 describes development of the remote psychoacoustic test platform used for this Feasibility Test; Section 3 describes stimuli; Section 4 details the Feasibility Test execution in the fall of 2022.

Staff at NASA Langley Research Center led a team of contractors to produce and execute the study, primarily Arup, Harris Miller Miller & Hanson Inc. (HMMH) and Westat Inc. (Westat).

### *1.2. Test Objectives*

The objectives of the Feasibility Test were:

1. Compare annoyance responses to those obtained for the same stimuli from a previous psychoacoustic test conducted in a controlled in-person test facility.
2. Demonstrate the ability to rank sounds by their annoyance response.
3. Determine if providing a contextual cue to test subjects produces a significant change in the annoyance response compared to not providing the cue.
4. Demonstrate the ability to compare responses from test subjects grouped by geographic location.
5. Identify potential administrative and technical challenges in using the remote test platform for the implementation phase of the UAM vehicle noise human response study.

While other remote testing efforts have shown good agreement with in-person laboratory testing [4, 5, 6], the goal of Objective 1 was to compare remote Feasibility Test results with a previous in-person test conducted at NASA Langley. Stimuli for the Feasibility Test were drawn from the in-person test. This in-person test determined the annoyance response to small Uncrewed Aerial System (sUAS) flyover sounds and ground vehicle sounds [7]. Section 5 provides Objective 1 results.

The goal of Objective 2 was to demonstrate a ranking capability that could be useful for UAM vehicle manufacturers as they consider the design and deployment of their vehicles. Section 5 compares sound rankings between the remote and in-person tests as an additional measure of Feasibility Test performance.

Objective 3 examined whether a contextual cue significantly affects laboratory test responses. Contextual cues refer to instructions such as telling a test subject to respond after "imagining they are at home" or "thinking about the past week." Such cues have been provided for in situ community response testing including the Federal Aviation Administration's Neighborhood Environmental Survey [8]. However, no such contextual cue was provided in the previous in-person test from which the Feasibility Test stimuli were drawn. Test subjects were simply asked, "How annoying was the sound to you?" after hearing the sound. The answer to this question on the influence of contextual cue on noise response is important for relating laboratory results to community testing where multiple sounds from an aircraft fleet may be heard. Reference [9] reviewed findings regarding contextual cues from previous laboratory psychoacoustic tests conducted at NASA. The previous research indicated test subject responses were noticeably affected depending on whether they were told to consider a nighttime or daytime context. The Feasibility Test does not involve nighttime noise response. Therefore, from these limited previous studies, a hypothesis for the Feasibility Test was that providing a contextual cue would not significantly affect responses.

To test this hypothesis regarding the influence of contextual cue, Feasibility Test subjects were evenly divided into "With-Cue" and "No-Cue" groups. After each sound stimulus was played, test subjects were asked a question unique to their group. The "No-Cue" group was asked the same annoyance response question from the previous in-person test:

> *"How annoying was the sound to you?"*

The "With-Cue" group was asked the following question:

> *"Imagine hearing this sound several times each day while outdoors and near your home, how annoying would this sound be to you?"*

Reference [9] explains the contextual cue development for the Feasibility Test. Section 6 compares the responses from the two different groups.

For Objective 4, Section 7 explores response differences among test subjects grouped by geographic region.

As part of Objective 5, Section 8 discusses the administrative and technical challenges encountered when conducting the Feasibility Test and improvements to the remote testing approach.

## 2. NASA Remote Psychoacoustic Testing Platform

### *2.1. Test Application Flow*

The NASA remote psychoacoustic test platform, which will be referred to as the remote test platform, was hosted on the NASA Amazon Web Services (AWS). The remote test platform was accessed through a web browser from the test subject's computer. The application was designed to work on personal computers or laptops running the Microsoft Windows or Apple macOS operating systems. Test subjects listened to stimuli using their own headphones.

A flowchart of the test process is illustrated in Figure 1. The solid arrows indicate the normal flow of the test, whereas long-dashed arrows indicate steps that may be repeated; dotted arrows exit the test. At any point during the test, subjects could contact test support.

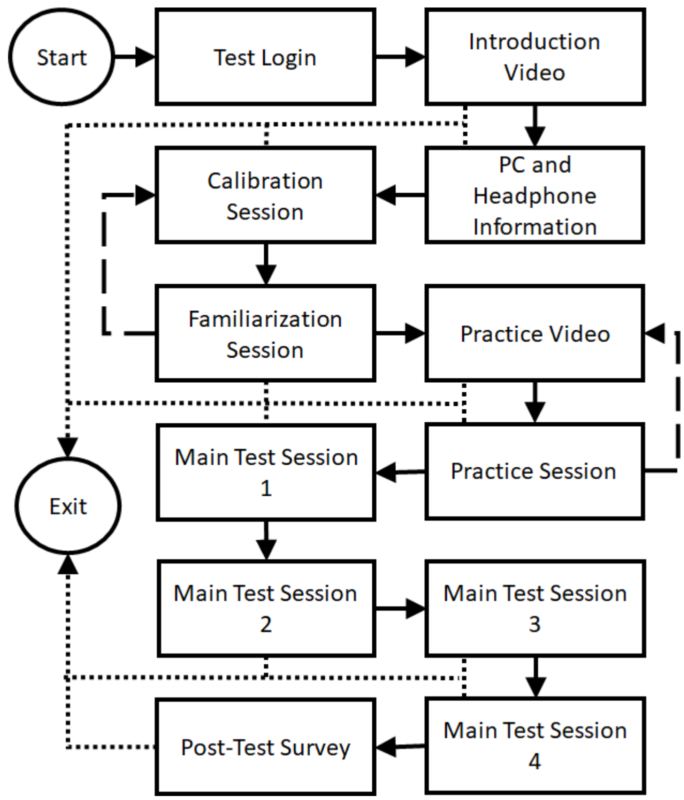


Figure 1. Remote Feasibility Test Flowchart.

Test subjects initially logged into the application using two-factor authentication. They were then guided to select the "NASA Psychoacoustic Sound Study" as shown in Figure A 1, in Appendix Section A1. Test subjects then watched an eight-minute introductory video on the test, which presented the following:

- Consent and privacy notices.
- A statement that their name, email address, and phone number will not be shared outside of the test.
- A statement that the only personal information used in analyses will be United States Zone Improvement Plan (ZIP) Code.
- That they had the ability to exit the test at any point.

- A brief overview of psychoacoustics and NASA's interest in understanding human response to aviation noise.
- A recommendation to use over-the-ear headphones, preferably wired headphones, for better frequency response (e.g., no compression from Bluetooth) and reduce unwanted noise.
- A recommendation to be in a quiet setting.
- The list of steps in the test (e.g., Introduction, Calibration, Familiarization).
- An email and phone number for test support.

The introductory video is available online [10].

Test subjects were then asked to enter the manufacturer make and model of their computer and headphones. This information could be used to understand the spectral characteristics of their sound system and explain outlier test subject responses, but this is not explored here. Test subjects could select "I don't know" to these questions.

Test subjects then began the Calibration session. The test application did not have access to the computer sound card and speaker system to adjust or read settings and volume. The calibration process asked test subjects to rub their hands together and adjust the volume on their computer to match a recorded sound of hands being rubbed together. Section 2.2 provides additional details of the calibration approach. After Calibration, test subjects were requested not to adjust the volume on their computers or headphones in subsequent steps.

After Calibration, test subjects began the Familiarization session where they listened to 10 sounds spanning the range of sound types they would encounter in the Main Test. The Familiarization session lasted 3 minutes and 49 seconds, and the Familiarization sounds are available online [10]. Test subjects did not answer any questions during the Familiarization step. After the sounds finished playing, test subjects could repeat the Calibration step or repeat the Familiarization sounds.

Test subjects were then shown a tutorial video on the mechanics of taking the test followed by a Practice session. The tutorial video included statements that test subjects will have time to take breaks between Main Test sessions and that they may leave the test website idle for up to six hours before automatically being signed out. The Practice session played only one sound to test subjects followed by an annoyance question prompt. The tutorial video and question prompt used in the Practice session contained the appropriate contextual cue (No-Cue or With-Cue) for each test subject. Test subjects could repeat the Practice session if desired. The tutorial videos and Practice sounds are available online [10].

During the Practice and Main Test sessions, subjects were asked to rate the annoyance of individual sounds using the prompts shown in Figure A 2. The test subject could not take any action while a sound stimulus was playing. After the stimulus finished playing, subjects used the response slider to indicate their level of annoyance. The adjectives on the slider, "Not at All," "Slightly," "Moderately," "Very," and "Extremely," guided the responses. The test platform assigned numerical values to the responses ranging from 1.00 to 11.00, which were not revealed to the test subjects. An annoyance rating of "Not at All Annoying" corresponded with a numerical rating of "2," and an annoyance rating of "Extremely Annoying" corresponded with a numerical rating of "10." Therefore, a numerical rating of "1" corresponded with an annoyance rating below "Not at All Annoying," and a numerical rating of "11" corresponded with an annoyance rating above "Extremely Annoying." After selecting an annoyance rating, the subjects confirmed their response before continuing to the next sound.

Seventy-six sounds were played to test subjects in the Main Test. The Main Test consisted of four sessions of 19 sounds each, with breaks between each session.

After completing the Main Test sessions, test subjects were asked two questions for a Post-Test Survey. The first question was whether they adjusted the volume on their headphones or computer after the Familiarization step. The second question gave subjects the opportunity to indicate potential difficulties they may have had during the test. They were offered 11 choices, and subjects could elaborate on their difficulties in a text entry field.

## *2.2. Calibration Method*

One of the key challenges with a remote psychoacoustic test is calibration of the stimulus signals. As the headphone and computer hardware are provided by the subject, variability in the hardware (e.g., frequency response of headphones, audio card quality and system settings) and environment (e.g., background noise where subject is taking test) can be significant. To enhance the accuracy of the stimuli, three elements were addressed in the calibration process: environmental noise control, platform streaming frequency response, and audio output level.

During the Calibration Session, the graphic in Figure 2 was displayed to prompt subjects to evaluate and adjust their ambient acoustic environment as needed. This was done to reduce aural and visual cues that may interfere with the subject's focus or audibility of the stimuli.


Figure 2. Graphic to adjust ambient environment.

When developing the Calibration method, a goal was to have a simple, reproducible method to generate a broadband sound level that participants can generate on their own to calibrate the laptop and headphones. The approach selected was based on research conducted for rapid evaluation of hearing loss during neurologic exams and requires the subject to rapidly rub their hands together in front of their face [11].

Figure 3 presents the measured one-third octave band spectrum of a typical hand rubbing from a 1 ft (30 cm) distance. The spectrum is generally broadband with more energy above 1 kHz. The spectrum indicates the signal is viable for calibration based on its energy content from 1 kHz to 5 kHz.

The level calibration procedure is as follows:

- Listen over headphones to a recording of hands rubbing together.
- Remove the headphones and rub hands together quickly and firmly 1 ft (30 cm) in front of your face.
- Put the headphones back on and listen to the hand rubbing recording again.
- Adjust the master volume level on your computer until the recording and hand rubbing have similar sound levels.
- Repeat the previous steps until the sound levels subjectively match.

The Calibration Session provided volume adjustment instructions based on the user's computer platform (Microsoft Windows or Apple macOS).

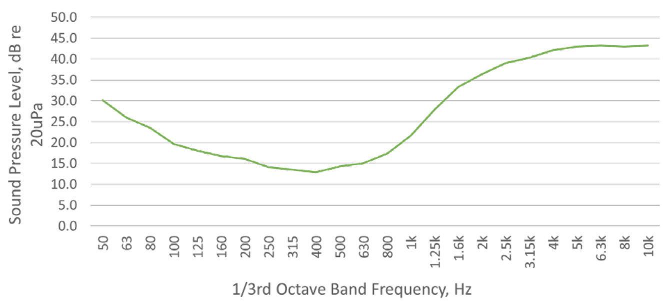


Figure 3. Recorded hand rubbing spectrum.

A pilot study was conducted to quantify variation in the hand rubbing stimuli. Twenty-five staff working with the research team from different offices were recruited and recorded 108 hand rubbings. The staff were encouraged to make multiple recordings, varying their technique to help diversify the data set. The distance from the measurement devices was fixed. The data were reviewed for anomalies in hand rubbing frequency and background noise (e.g., voices, cellphone alerts) with 7 out of the 108 recordings rejected as anomalous. Figure 4 gives the equivalent continuous sound level distribution from the remaining recordings. The distribution peaks at 32-34 dBA with a standard deviation of 4.3 dBA, indicating most of the calibration stimuli are going to be within a 4 dBA spread. No significant differences were found in the hand rubbing sound levels from different office locations.

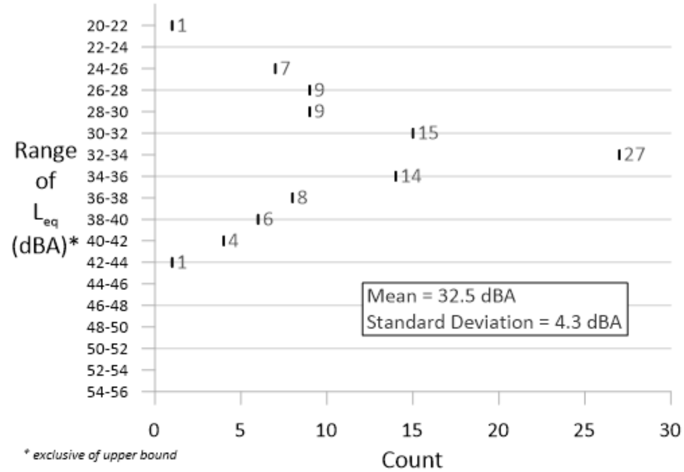


Figure 4. Distribution of measured hand rubbing sound levels.

## *2.3. Remote Test Platform Development*

### 2.3.1. User Interface

The remote test platform user interface is deployed in common browser environments. The user interface for the remote test platform is built using the React framework, which accelerates common programming tasks when creating and maintaining website functions (e.g., HTML and JavaScript interfaces). React utilizes Node.JS, which is a server-side framework which facilitates secure delivery of the user interface to the browser. Node.JS utilizes an AWS Amazon Elastic Compute Cloud server. Feasibility Test subjects were encouraged to use either the Google Chrome, Microsoft Edge, or Mozilla Firefox web browsers. No plugins, add-ons, or other changes are needed for the software to function.

### 2.3.2. Accessibility

The user interface was designed to comply with Section 508 of the United States' Rehabilitation Act of 1973, which requires Federal agencies to make their electronic and information technology (EIT) accessible to people with disabilities. The software design applies best practices for fonts, colors, and layout of the user interface, and uses Accessible Rich Internet Applications tags (ARIA) for describing elements in the user interface needed to complete tasks in conjunction with assistive technologies.

### 2.3.3. Security

Every interaction between the browser and server is encrypted utilizing the Cognito toolset from AWS to allow user management in compliance with information technology security requirements. This includes two-factor authentication (2FA), which requires users to provide an email address and phone number when registering for access. With 2FA, the user logs in with their email and password and is then prompted to provide a code texted to their phone number.

The AWS Key Management Service generated and stored all keys needed for test administrators to access the remote test platform on the server-side and limit server-side access to specific test administrators.

All data stored and generated by the remote test platform was resident within the United States.

### 2.3.4. Server Application

The server side of the remote test web application is built utilizing AWS Lambda functions. Lambda functions allow user interactions with the test application interface using JavaScript Object Notation (JSON) which is an industry standard mechanism for data transmission. Separate JSON descriptors were generated for the following data:

- All sounds for the test and associated annoyance prompts (No-Cue or With-Cue).
- The order in which stimuli are presented to each test subject.
- Test subject responses for each sound. Responses are sent to the server only at the conclusion of the test to facilitate test subjects completing the test in one sitting. However, this meant that test subjects had to restart the test if they exited before completion. The effects of restarting the test are discussed in Sections 4.4 and 8.
- A log of interactions to diagnose technical problems encountered by the user.

### 2.3.5. Audio File Playback

The test framework utilizes AWS Simple Storage Service (S3), commonly referred to as an "S3 bucket" to store the stimuli audio files and provide them to a test subject's browser. Files were stored using the common lossless Waveform (WAV) format to maintain required audio quality for testing.

The WAV file does not need to be downloaded completely but begins playing as soon as enough data for the playback is retrieved. The WAV file is not cached and hence is not saved to the browser. The user interface and React framework validate the file is successfully playing. Playback fidelity was verified during remote test platform development by comparing original and playback pink noise bursts, chirp signals, and speech.

## 3. Test Stimuli

All stimuli for the Feasibility Test were drawn from the NASA Design Environment for Novel Vertical Lift Vehicles psychoacoustic test, which is referred to as WGA-I [7]. This in-person test was conducted in February 2017 in the NASA Langley Research Center Exterior Effects Room (EER) [12]. WGA-I stimuli consisted of recorded sUAS flyovers, recorded ground vehicles in motion, sUAS flyover auralizations, and Distributed Electric Propulsion (DEP) aircraft auralizations. Auralizations are sounds generated from numerical data [13]. The sounds were presented using the 3D sound reproduction capability of the EER. WGA-I tested 38 test subjects in the EER. After test subjects were played a sound, they responded to the question "How annoying was the sound to you?"

To provide remote test subjects a shorter test, only 72 of the 103 WGA-I stimuli were used in the Main Test portion of the remote Feasibility Test. Feasibility Test stimuli are listed in Table A 1 Appendix Section A2, with an "M" in the "Test Session" column of Table A 1. The playback sequence of the 72 Main Test sounds was unique for different subjects to minimize the effects of ordering bias. All Feasibility Test stimuli were binaural with sound sources moving from left-to-right with respect to a stationary listener. WGA-I stimuli that had front-to-back noise source motion were excluded from the Feasibility Test. Although ambient noise was added to the stimuli for WGA-I, no ambient noise was added to the stimuli used for the Feasibility Test.

One of the main results of interest from WGA-I is that it found a significant difference between annoyance responses to sUAS noise and ground vehicle noise. Figure 5 regenerates this result using WGA-I responses but only for sUAS and ground vehicle stimuli that are among the 72 Feasibility Test stimuli.[1] Each marker in Figure 5 is the mean annoyance response, with a 95% confidence interval, to a sound from all 38 WGA-I test subjects. Augmented linear regression fit two lines to the data: one for responses to sUAS recorded flyover sounds and one for responses to the ground vehicle sounds, both as a function of the intended Sound Exposure Level, A-weighted, (SELA).[2] Both regression lines in Figure 5 were assumed to have the same slope A coefficient of determination value, $R^2$, of 0.82 indicates the regression line pair captures the annoyance variation relatively well. The SELA offset between the sUAS flyover sounds and ground vehicle lines is 4.14 dB, meaning an sUAS flyover with a SELA that is approximately 4.14 dB lower will generate a similar annoyance response to a ground vehicle. Bootstrapped regressions, as described in Ref. [7], generated a 95% confidence interval (CI) of [-5.7, -2.6] dB for the SELA offset. The confidence interval does not contain 0 dB, indicating that there is a significant difference between responses to sUAS noise and ground vehicle noise. Objective 1 will compare Figure 5 results against Feasibility Test results.

A Familiarization Session consisting of ten sounds was played to test subjects. The sounds and their presentation sequence were the same as those used in the familiarization session for WGA-I. Table A 1 gives the Familiarization Session sounds with an "F" in the Test Session column.

Although five practice sounds were used in WGA-I, the remote test platform software allowed only a single practice sound to be used. To maintain consistency between the tests, the first WGA-I Practice sound, an SUI flyover (see Table A 1), was used as the Practice sound for the Feasibility Test, and the remaining four WGA-I practice sounds were used as the first four sounds of the Main Test, played to all test subjects in the same sequence as in the WGA-I practice session. However, responses to these four sounds were treated as practice sounds and were not analyzed with the Main test

[1] The original WGA-I result in Ref. [7] comparing sUAS and ground vehicle noise annoyance response was generated by excluding some sUAS sounds and excluding all the auralizations. Figure 5 also excludes the sounds that were excluded in the Ref. [7] results.

[2] Figure 7 refers to the stimuli SELA values as "Intended SELA" because they were computed directly from the stimuli WAV files using the same SELA calculation algorithm used for WGA-I, described in Ref. [7]. This algorithm requires monaural WAV files as input, hence the SELA values for the Feasibility Test stimuli were computed before they were rendered binaurally. Table A 1 gives the intended SELA levels of the Feasibility Test stimuli.

sounds. With the addition of these four sounds, the total number of sounds in the Main Test became 76. Table A 1 in Section A2 gives the Practice Session sounds with a "P" in the Test Session column.

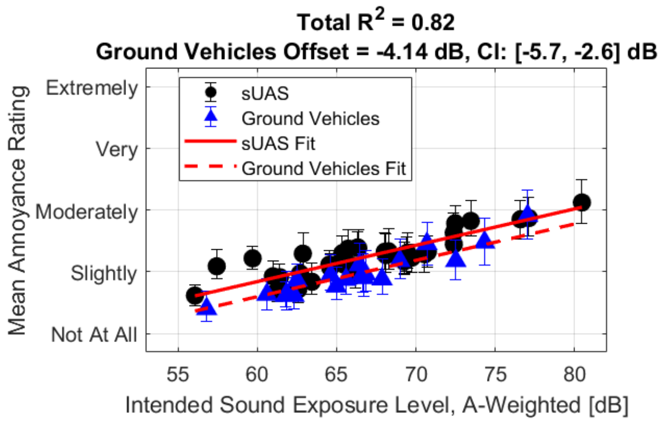


Figure 5. WGA-I annoyance against intended SELA to only Feasibility Test Stimuli.

# 4. Feasibility Test Administration

## *4.1. Test Approvals*

The test execution protocol was reviewed and approved by an Institutional Review Board (IRB). In addition, a Privacy Impact Assessment was conducted to document risks and develop mitigation strategies to inadvertent release of Personal Identifiable Information (PII) of test subjects.

The United States Office of Management and Budget provided Paperwork Reduction Act approval for the Feasibility Test public data collection method with control number 2700-0190. A Paperwork Reduction Act Statement was provided to test subjects at the start of the test application.

## *4.2. Test Subject Recruitment*

Volunteer test subjects were recruited from NASA centers, UNWG participants, and staff from the contractor team companies. One hundred forty-six persons volunteered and were then asked to complete a questionnaire that collected contact information and demographic data (age range, gender, United States ZIP code, self-reported hearing loss, and self-reported attestation that they were not aviation noise subject matter experts). A volunteer was not permitted to participate if they reported having hearing loss or reported that they were aviation noise subject matter experts. A female-to-male gender ratio of study participants was required to be between 1:3 and 2:3. Eighty-six of the original 146 volunteers provided sufficient information in the questionnaire to participate in the study.

Test administrators used volunteer gender and geographic location to divide participants into geographic and contextual cue groups. The locations of the participants were estimated based on their ZIP code. Of the possible geographic groupings, the contiguous United States east-west divide, created by drawing a north-south line along the Mississippi River, was chosen to have the closest balance of total participants and gender, with 46 people in the "east" group and 40 in the "west." Each geographic group was then split into equal-sized No-Cue and With-Cue sets.

## *4.4. Test Execution*

The Feasibility Test was started on Saturday, October 15, 2022, and concluded on Sunday, October 30, 2022. Technical issues and a low response rate necessitated an extension of the test beyond its original October 22 end date. Multiple email reminders were sent to encourage participants to complete the test during the allotted time. The test extension greatly increased the number of participants who completed the test. Technical support via an email account and phone hotline were provided during the test.

To protect the identity of the test subjects, their responses, Main Test stimuli sequence, contextual cue group, and United States ZIP code were labeled with a unique Cognito-generated ID number. Feasibility Test responses consisted of a consent indicator to take the test, the annoyance rating for each stimulus, Main Test stimuli response times, self-reported computer volume level from Calibration, self-reported computer and headphone make/model, and Post-Test Survey responses. Age range and gender distribution were reported in aggregate and were disassociated from individual test subjects. No other test subject information was reported to NASA.

Forty-eight of the original 86 subjects fully completed the test. Table 1 decomposes these 48 test subjects by contextual and geographic group. The gender distribution of these 48 test subjects was 29 male and 19 female, which met the required gender ratio. Test subjects required an average of 51 minutes to complete the Main Test, with a range of 32 minutes to just under 5 hours. None of the 48 test subjects reported in the Post-Test Survey that they changed their computer volume during the test.

Table 1. Number of subjects who completed Feasibility Test in geographic and contextual-cue groups.

| Test Subject Groups | No-Cue | With-Cue | Both Contextual Cue Groups |
|---|---|---|---|
| Geographic East | 13 | 14 | 27 |
| Geographic West | 13 | 8 | 21 |
| Both Geographic Groups | 26 | 22 | 48 |

Figure 6 gives the subject age distribution for the 48 "Respondents" and 86 in the recruitment set. There were at least three test subjects in each age range category who completed the test. The average age range was 35-49 years.

Seventeen of the 38 test subjects who did not complete the test attempted it but exited before reaching the end of the test. Because no specific test response information was available on the 17 incomplete accounts, a post-test questionnaire was sent to those participants. Two responses to the questionnaire were received. Both responses are paraphrased: (1) "An extra week or two weeks is needed for me to complete the test." and (2) "Having the ability to restart the test from where I had previously exited would have helped me finish the test."

Figure 6. Age distribution of Feasibility Test subjects.

## 5. Replicating In-Person Test Results

Figure 7 compares annoyance responses from the Feasibility Test No-Cue group as a function of intended SELA values to the WGA-I annoyance responses. The red traces in Figure 7 correspond to the WGA-I response regression lines previously shown in Figure 5. The green regression lines correspond to the Feasibility Test results and indicate a larger offset between sUAS and ground vehicle responses than was seen in the WGA-I test. Nonetheless, as these data indicate, the Feasibility Test replicated the WGA-I test by identifying a statistically significant difference between sUAS noise and ground vehicle noise annoyance response regression lines as a function of SELA (Objective 1). A potential cause for the larger offset may be differences between the EER frequency response for WGA-I test subjects and headphone frequency responses for Feasibility Test subjects, but this paper does not explore potential reasons for the larger offset relative to the WGA-I test subjects. Stimuli ordering was evenly spread among the 48 respondents, making it unlikely that Figure 7 results were biased by sound presentation sequence.

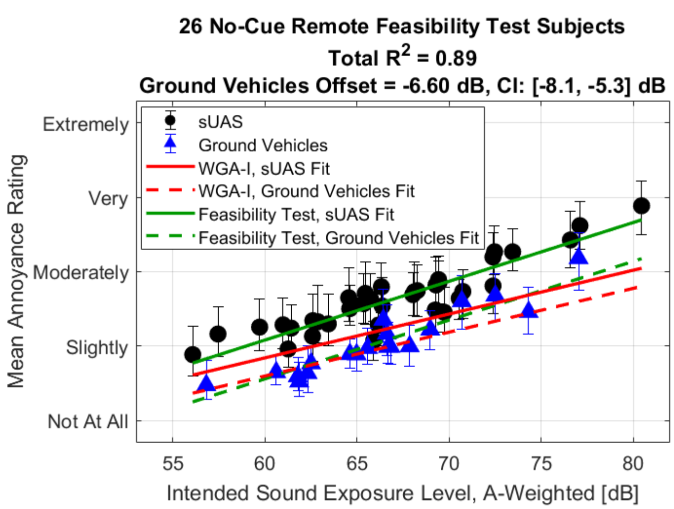

Figure 7. Comparison of human response to sUAS and ground vehicle noise between WGA-I Test and Remote Feasibility Test.

Ranking sounds by their mean annoyance response (Objective 2) is another method to compare the Feasibility and WGA-I tests. Figure 8 shows a sound's ranking in WGA-I plotted against its rank from the Feasibility Test; perfect agreement corresponds to the black line. Figure 8 shows that the in-person and remote test subjects were more consistent in their annoyance response rankings to the most and least annoying sounds but were less consistent for mid-ranged sounds (sounds with WGA-I annoyance rankings from approximately 22 to 65). The overall trend does not reveal any consistent bias or difference between the two tests.

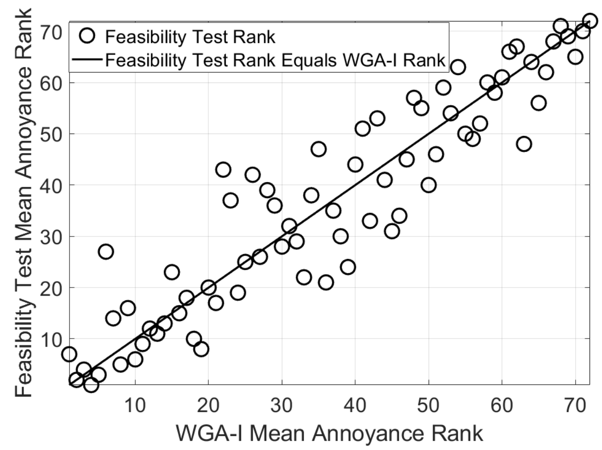

Figure 8. Comparing WGA-I and Feasibility Test Mean Annoyance Ranking.

## 6. Response Dependency on Context

### *6.1. The Sign Test*

To explore the impact of different factors on the annoyance response using a method that is independent of a specific noise metric, this paper uses the Sign Test method, as described in section 10.8 of Ref. [14]. The Sign Test is used here to compare the median annoyance between two groups of subjects. The Sign Test does not require any distributional assumptions on the annoyance responses. The first step is to define the two groups of test subjects and their annoyance responses as Groups $G = 1$ and $G = 2$. The number of annoyance responses in each group is equal to the number of test subjects in the group multiplied by the number of sounds. Let variable $\bar{G} = 1$ when $G = 2$, and $\bar{G} = 2$ when $G = 1$. Note that the number of annoyance responses in Group $G$ may not be equal to the number of annoyance responses in Group $\bar{G}$. Let $\mu_G$ be the median annoyance response of Group $G$ to sounds and let $\mu_{\bar{G}}$ be the median annoyance response of Group $\bar{G}$. The Sign Test will test the following hypotheses:

$$\begin{aligned} H_{G,\text{null}} &: \mu_G = \mu_{\bar{G}} \\ H_{G,\text{alt}} &: \mu_G \neq \mu_{\bar{G}} \end{aligned} . \quad (1)$$

In Eq. (1), $H_{G,\text{null}}$ is the null, or equality, hypothesis, and $H_{G,\text{alt}}$ is the alternative, or inequality, hypothesis. The hypotheses in Eq. (1) will be tested for $G = 1$ and again for $G = 2$. At first, it may appear that the two tests are identical, but the p-value, $\alpha_{G,p}$, calculated for the tests, may be different due to differences in the number of responses and response values for the two groups. In this paper, the p-value, which is a probability value, in each of these tests is a measure of being correct or incorrect if accepting $H_{G,\text{null}}$ or $H_{G,\text{alt}}$, respectively.

The Sign Test will calculate $\alpha_{G,p}$ using all the responses in Group $G$ to compare against the single, or scalar, value, $\mu_{\bar{G}}$. The Sign Test decides which hypothesis in Eq. (1) to reject at a level of significance $\alpha_0$ according to

$$\begin{array}{l} \text{Reject } H_{G,\text{null}} \text{ and accept } H_{G,\text{alt}} \text{ if } \alpha_{G,p} \le \alpha_0 \\ \text{Reject } H_{G,\text{alt}} \text{ and accept } H_{G,\text{null}} \text{ if } \alpha_{G,p} > \alpha_0 \end{array}. \quad (2)$$

In this paper, the median annoyance values between two groups will be considered significantly different if the null hypothesis, $H_{G,\text{null}}$, is rejected for $G = 1$ and $G = 2$, at level $\alpha_0$. If the two groups are considered significantly different, then for $\mu_G > \mu_{\bar{G}}$, the median of Group $G$ will be considered significantly greater than the median of Group $\bar{G}$.

### *6.2. Contextual Cue Testing Results*

To evaluate the effect of contextual cue, the Sign Test method was used to compare median annoyance responses for the No-Cue group (labeled $G = 1$ here) and the With-Cue group ($G = 2$). Table 2 gives the Sign Test results from comparing median annoyance responses to each vehicle type (sUAS and ground vehicles) for the two subject groups. The $\mu_1$ ($G = 1$) and $\mu_2$ ($G = 2$) columns give the median annoyance responses, which show that the With-Cue subjects had a larger median annoyance response to sUAS noise than No-Cue test subjects. For the sUAS noise responses, the Sign Test p-values for both subject groups, $\alpha_{1,p}$ and $\alpha_{2,p}$, are extremely low. These p-values lead to the acceptance that the With-Cue median sUAS noise annoyance response is significantly greater, statistically, at a significance level of $\alpha_0 = 0.05$, than the No-Cue median sUAS noise annoyance response. For the ground vehicle noise responses, although the No-Cue median annoyance response is greater than that of With-Cue, the p-values being greater than 0.05 for tests on both subject groups indicate acceptance of the hypothesis that the median ground vehicle noise annoyance responses between No-Cue and With-Cue test subjects are equal. Stimuli ordering was evenly spread among the No-Cue and With-Cue respondents, making it unlikely that Table 2 results were biased by sound presentation sequence.

These results indicate that a contextual cue is important for sUAS noise or similar sounds, and hence should be used if the results of the remote test are to be compared with community noise testing, where contextual cues are routinely provided.

The possible impact of self-reported computer volume level on the Table 2 results was also considered. The median computer volume levels over test subjects, given as percentages of the maximum computer volume level, for the No-Cue and With-Cue test subjects were 50.0% and 55.5%, respectively. Sign Tests on median computer volume levels between the two groups gave p-values of $\alpha_{1,p} = 0.85$ for No-Cue ($G = 1$) and $\alpha_{2,p} = 0.83$ for With-Cue ($G = 2$). Therefore, the median computer volume levels of 50.0% and 55.5% are not significantly different at a significance level of $\alpha_0 = 0.05$. Hence, computer volume level differences among test subjects were likely not contributors to Table 2 results.

Table 2. Sign Test results comparing vehicle type responses between No-Cue ($G = 1$) and With-Cue ($G = 2$) test subjects. Units for $\mu_{G=1}$ and $\mu_{G=2}$ are annoyance ratings.

| | **Median Annoyance** | | **p-Values [Probability]** | | |
|---|---|---|---|---|---|
| **Vehicle Type** | $\mu_{G=1}$ | $\mu_{G=2}$ | $\alpha_{G=1,p}$ | $\alpha_{G=2,p}$ | **Accepted Sign Test Results** |
| sUAS | 5.07 | 6.00 | 1.5e-20 | 1.5e-14 | $H_{G=1,\text{alt}}$, $H_{G=2,\text{alt}}$ |
| Ground Vehicles | 3.93 | 3.75 | 0.28 | 0.41 | $H_{G=1,\text{null}}$, $H_{G=2,\text{null}}$ |

## 7. Responses by Geographic Region

### *7.1. Geographic Region Testing Results*

The influence of geographic region on response was also explored using the Sign Test method. For this analysis, only the sUAS responses were considered to ensure relevance of the conclusions to a future UAM human response study.

Table 3 gives the Sign Test results between groups of test subjects in the East and West geographic regions. The 21 test subjects in the West geographic region had a higher median annoyance response to sUAS noise than the 27 test subjects in the East geographic region. The data for both groups support rejecting the hypotheses that their median annoyance response values are the same at a $\alpha_0 = 0.05$ significance level. Thus, for this population, sUAS noise was found to be more annoying by subjects in the West geographic region than in the East region.

Table 3. Sign Test results comparing East and West test subjects.

| **Group Name** | $\mu_G$ **[Median Annoyance Rating]** | **p-Value,** $\alpha_{G,p}$ **[Probability]** | **Accepted Sign Test Result** |
|---|---|---|---|
| East ($G = 1$) | 5.02 | 3.3e-18 | $H_{G=1,\text{alt}}$ |
| West ($G = 2$) | 6.00 | 6.4e-23 | $H_{G=2,\text{alt}}$ |

Table 4 contains Sign Test results on contextual cue differences by geographic region. These results compare median annoyance responses to sUAS noise within a geographic region (East or West) between No-Cue test subjects (Group $G = 1$) and With-Cue test subjects (Group $G = 2$). The $\mu_{G=1}$ and $\mu_{G=2}$ columns give the median annoyance responses, which show that the With-Cue subjects had higher median annoyance to sUAS noise than No-Cue test subjects. Within each region, Sign Tests for the two contextual cue subject groups lead to rejection of the hypothesis that median annoyance responses are equal, at a significance level $\alpha_0 = 0.05$. Thus, the importance of contextual cue in the annoyance response to sUAS noise response applies to both geographic regions.

Stimuli ordering was evenly spread among respondents in the East, West, and No-Cue and With-Cue within these two geographic regions. It is unlikely that results in Tables 3 and 4 were biased by sound presentation sequence.

Table 4. Sign Test results comparing responses within geographic regions between No-Cue ($G = 1$) and With-Cue ($G = 2$) test subjects. Units for $\mu_{G=1}$ and $\mu_{G=2}$ are annoyance ratings.

| | Median Annoyance | | p-Values [Probability] | | |
|---|---|---|---|---|---|
| **Geographic Region** | $\mu_{G=1}$ | $\mu_{G=2}$ | $\alpha_{G=1,p}$ | $\alpha_{G=2,p}$ | **Accepted Sign Test Results** |
| East | 4.32 | 5.99 | 4.7e-26 | 2.9e-24 | $H_{G=1,\text{alt}}$, $H_{G=2,\text{alt}}$ |
| West | 5.97 | 6.16 | 1.7e-6 | .0038 | $H_{G=1,\text{alt}}$, $H_{G=2,\text{alt}}$ |

## *7.2. Computer Volume Effects*

The possible influence of self-reported computer volume level on annoyance response was also explored using the Sign Test method. Sign Tests between East and West test subjects and Sign Tests between East-No-Cue and East-With-Cue test subjects did not find a significant difference in their median self-reported computer volume levels at a significance level of $\alpha_0 = 0.05$.

However, median computer volume levels for test subjects in the West-No-Cue and West-With-Cue groups were 37.0% and 66.0%, respectively. Sign Tests gave p-values of $\alpha_{1,p} = 0.022$ for West-No-Cue ($G = 1$) and $\alpha_{2,p} = 0.0078$ for West-With-Cue ($G = 2$), indicating rejection of the null hypothesis that the sound levels were equal at a significance level of α_0=0.05.

Figure 9 shows the computer volume levels for the two groups. None of the subjects in the West-With-Cue group had volume levels below 40.0%, whereas more than half the subjects in the West-No-Cue group had levels below 40%.

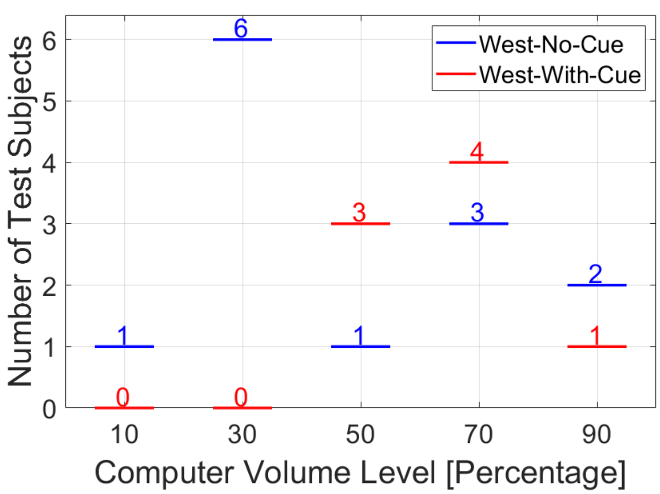


Figure 9. Computer volume level distribution for West test subjects.

The West-No-Cue group was modified to only include the six test subjects with self-reported computer volume levels greater than 40.0%. These test subjects will be referred to as West-No-Cue-Mod. From Table 5, the West-No-Cue-Mod median annoyance rating of 5.45 is lower than both the West-With-Cue annoyance rating of 6.16 and the West-No-Cue annoyance rating of 5.97 in Table 4. From the Sign Test p-values given in Table 5, all eight of the West-With-Cue test subjects gave a median annoyance response significantly greater than the median annoyance response of the West-No-Cue-Mod group. The results of the Sign Tests, at a significance level $\alpha_0 = 0.05$, indicate the null hypothesis (of equality) should be rejected.

Table 5. Sign Test results for West test subjects with modified No-Cue group ($G = 1$) and original With-Cue group ($G = 2$).

| Group Name | $\mu_G$ [Median Annoyance Rating] | p-Value, $\alpha_{G,p}$ [Probability] | Accepted Sign Test Result |
|---|---|---|---|
| West-No-Cue-Mod | 5.45 | 2.5e-7 | $H_{G=1,\text{alt}}$ |
| West-With-Cue | 6.16 | 8.5e-7 | $H_{G=2,\text{alt}}$ |

The varied Feasibility Test computer volume levels appear to be more a reflection of the Calibration's normalization rather than of true varied sound levels. This assessment is based on 1. assuming higher true sound levels lead to higher annoyance, 2. the No-Cue median annoyance rating reduced in Table 5 when focusing on test subjects who set high computer volume levels, and 3. Tables 2, 4, and 5 showing With-Cue test subjects maintaining significantly higher median annoyance response than No-Cue test subjects at a significance level of $\alpha_0 = 0.05$. Based on these results, the Feasibility Test Calibration method appeared to perform its function of normalizing sound levels at the subjects' ears enough to produce the statistically significant results in this paper.

# 8. Test Administration Results

Successes and challenges were documented in developing the remote test platform, planning the Feasibility Test, and executing the Feasibility Test. The following list includes items to repeat in future remote psychoacoustic testing and items that are among the most important to be addressed before applying the remote test platform to the implementation phase of the UAM vehicle noise human response study:

1. Prompt handling of bug reports from test subjects and remotely resetting tests for test subjects when needed.
2. Timely, concise communications from test administrators to test subjects. Test subjects were reminded once during the first week of testing and twice the second week of testing to complete the Feasibility Test, and a noticeable increase in test completions always followed shortly after these notifications. Extending the Feasibility Test by a week greatly increased the number of subjects who completed the test.
3. Consider allowing users to restart the test from where they last exited, rather than having to retake the test from the beginning.
4. Have some method of automatically monitoring the status of the test website and automatically restarting the application if it inadvertently stops.
5. Some test subjects found the test too long, so it may be useful to explore the tradeoff between providing a shorter test to more test subjects, by giving only part of the total stimuli suite to each test subject. This will require more test subjects and could complicate some studies requiring proportions of test subject representation (gender, cueing, or geography),

# 9. Summary/Conclusions

The NASA remote psychoacoustic test platform was tested and used to execute the Feasibility Test of the UAM vehicle noise human response study. Test subjects from across the contiguous United States took the Feasibility Test remotely through web browsers on their own computers and headphones. Test subjects calibrated their audio systems using a method where they rubbed their hands together and listened to a reference sound of hands being rubbed together. Feasibility Test sound stimuli came from a previous in-person test conducted in a controlled laboratory setting that compared human response to sUAS noise and ground vehicle noise. Out of 86 volunteers, 48 test subjects fully completed the Feasibility Test.

Results from Feasibility Test analyses are:

1. Replicating in-person test results with the Feasibility Test:
    a. The existence of an annoyance response difference between sUAS noise and ground vehicle noise in the in-person test was replicated in the Feasibility Test.
    b. The Feasibility Test had a larger annoyance response offset between sUAS and ground vehicle noise response than the in-person test.
    c. The ranking of sounds by mean annoyance response were roughly the same for the Feasibility Test and the in-person test.
2. Comparison of Feasibility Test No-Cue and With-Cue test subject group responses:
    a. For sUAS, differences in the overall noise annoyance response were detected between No Cue and With Cue groups
    b. For ground vehicle noise, differences in the overall noise annoyance response were not detected between No Cue and With Cue groups.
3. Regarding effect of respondent location on sUAS noise annoyance response in the Feasibility Test:
    a. Differences were detected between test subjects in the eastern and western United States
    b. No Cue/With Cue differences appear within geographic regions.
4. The Feasibility Test Calibration method appears to have adequately normalized test subject hearing.

Planning and executing the Feasibility Test gave insights that will be useful for planning and executing the implementation phase of the UAM vehicle noise human response study.

## Disclaimer

The use of trademarks or names of manufacturers in this paper is for accurate reporting and does not constitute an official endorsement, either expressed or implied, of such products or manufacturers by the National Aeronautics and Space Administration.

## References

1. D. P. Thipphavong, R. D. Apaza, B. E. Barmore, V. Battiste, et al., "Urban Air Mobility Airspace Integration Concepts and Considerations," in AIAA Aviation Forum, Paper 3676, Atlanta, Georgia, 2018.
2. L. Gipson, "Advanced Air Mobility Project," National Aeronautics and Space Administration, 7 October 2021. [Online]. Available: https://www.nasa.gov/aeroresearch/programs/iasp/aam/description/. [Accessed 8 March 2022].
3. S. A. Rizzi, D. L. Huff, D. D. Boyd, Jr., P. Bent, B. S., et al., "Urban Air Mobility Noise: Current Practice, Gaps, and Recommendations," NASA/TP–2020-5007433, October 2020.
4. E. S. Lelo de Larrea-Mancera, T. Stavropoulos, E. C. Hoover, D. A. Eddins, et al., "Portable Automated Rapid Testing (PART) for auditory assessment: Validation in a young adult normal-hearing population," The Journal of the Acoustical Society of America, vol. 148, no. 4, pp. 1831-1851, 2020.
5. E. Peng, E. Burg, T. Thakkar, S. Godar, et al., "Web-based remote testing as a viable option for measuring binaural hearing abilities," in The Journal of the Acoustical Society of America, 150, A300, 2021.
6. M. H. Ugolini, E. R. Thompson and F. S. Mobley, "A within-subject comparison of remote and in-laboratory methods for auditory detection studies," in The Journal of the Acoustical Society of America, 150, A301, 2021.
7. A. Christian and R. Cabell, "Initial Investigation into the Psychoacoustic Properties of Small Unmanned Aerial System Noise," in AIAA AVIATION Forum, Paper 4051, Denver, Colorado, 2017.
8. N. P. Miller, J. J. Czech, K. M. Hellauer, B. L. Nicholas, et al., "Analysis of the Neighborhood Environmental Survey," U.S. Department of Transportation, DOT/FAA/TC-21/4, 2021.
9. S. Krishnamurthy and S. A. Rizzi, "Feasibility study for remote psychoacoustic testing of human response to urban air mobility vehicle noise," in INCE NOISE-CON 2022, Paper 676, Lexington, KY, 2022.
10. "Aircraft flyover simulation," NASA, 2023. [Online]. Available: https://stabserv.larc.nasa.gov/flyover/.
11. D. Torres-Russotto, W. M. Landau, G. W. Harding, B. A. Bohne, et al., "Calibrated finger rub auditory screening test (CALFRAST)," Neurology, vol. 72, no. 18, pp. 1595-1600, 2009.
12. K. J. Faller II, S. A. Rizzi and A. R. Aumann, "Acoustic performance of a real-time three-dimensional sound reproduction system," NASA/TM-2013-218004, Hampton, VA, 2013.
13. S. A. Rizzi and A. K. Sahai, "Auralization of air vehicle noise for community noise assessment.," CEAS Aeronautical Journal, vol. 10, no. 1, pp. 313-334, 2019. doi: 10.1007/s13272-019-00373-6.
14. M. H. DeGroot and M. J. Schervish, "Sign and Rank Tests," in Probability and Statistics, D. Lynch, Ed., Pearson Education, Inc., 2012, pp. 678 - 680.

## Contact Information

Technical questions on the material in this paper may be addressed to the main author at:

Address: NASA Langley Research Center, 2 North Dryden Street, Mail Stop 463, Hampton, VA 23681.

Email: siddhartha.krishnamurthy@nasa.gov.

Phone: 757-864-7656.

## Acknowledgments

Development of the remote NASA Psychoacoustic Testing Library and execution of the Feasibility Test was supported by the Revolutionary Vertical Lift Technology Project of the NASA Advanced Air Vehicles Program and the Structural Acoustics Branch at the NASA Langley Research Center with primary contractor support from Analytical Mechanics Associates, Inc (AMA). The authors thank Bob Stephens, Erin Thomas, and Syed Rizvi of AMA for their support in managing and administering the psychoacoustic test for this project. Scott Lee of NASA HITSS Engineering, Aric Aumann of Analytical Services and Materials, Inc., and Dawayne Pretlor of NASA provided invaluable AWS and remote testing technical support.

## Definitions/Abbreviations

| | |
|---|---|
| **2FA** | Two-factor authentication. |
| **AWS** | Amazon Web Services. |
| **CI** | Confidence Interval. |
| **DEP** | Distributed Electric Propulsion. |
| **EER** | Exterior Effects Room. |
| **JSON** | JavaScript Object Notation. |
| **NASA** | National Aeronautics and Space Administration. |
| **PII** | Personal Identifiable Information. |
| **SELA** | Sound Exposure Level, A-weighted. |
| **sUAS** | small Uncrewed Aerial System. |
| **UAM** | Urban Air Mobility. |
| **UNWG** | UAM Noise Working Group. |
| **WAV** | Waveform audio file format. |
| **ZIP** | Zone Improvement Plan. |

# Appendix

## *A1. Screenshots of NASA Psychoacoustic Testing Library Web Application*

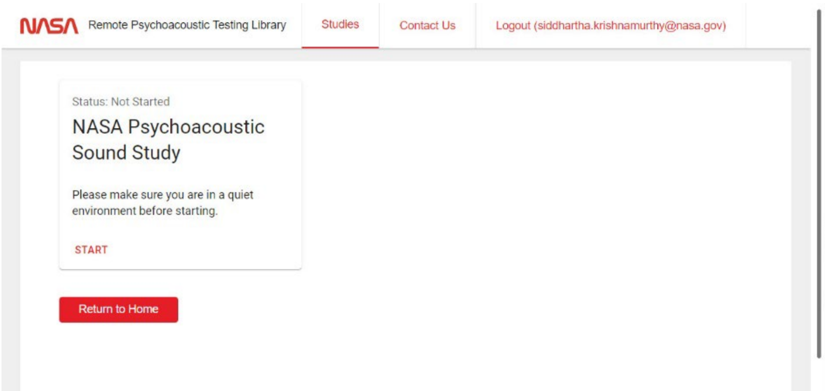


Figure A 1. Test Selection Page.

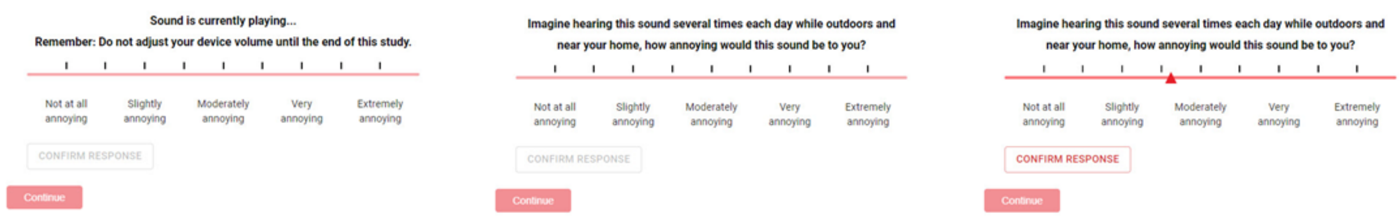


Figure A 2. Sequence of test question and response prompts. (Left) Question prompt when sound is playing. (Middle) Question prompt when sound finishes playing. (Right) Question prompt after test subject selects annoyance response. Example shown is for test subject in given-contextual cue group.

## *A2. Feasibility Test Stimuli List*

Table A 1 lists the Feasibility Test sounds. The Identification (ID) Number column is the sound ID number, which is the same as the ID number given for the sound in WGA-I. Rows with multiple ID numbers indicate duplicate sounds. Vehicle names (under vehicle column) and configurations (under configuration column) are as follows:

- sUAS stimuli (sound IDs 1 to 387)
  - Straight Up Imaging Endurance (SUI)
    - OEM-2: two-bladed configuration
    - OEM-3: three-bladed configuration
  - Drone America Dax 8 octocopter (Dax 8)
  - DJI Phantom 2 quadcopter (Phantom 2)
    - APC: "slow flyer" propeller manufactured by Advanced Precision Composites
    - CF: carbon fiber blades
    - OEM: standard Original Equipment Manufacturer (OEM) blades delivered with the vehicle
  - Stingray 500 variable pitch quadcopter (VPV).
- Ground vehicle stimuli (sound IDs 404 to 476)
  - Passenger hatchback automobile (Subaru)
  - Grumman Kurbmaster (Step Van)
  - International Harvester MaxxForce DT DuraStar (Box Truck)
  - Ford Econoline 350 (Utility Van).
- Auralizations (A "*" next to the vehicle name indicates the sound is an auralization)
  - Quadcopters (sound IDs 601 to 633)
    - Configuration 1: no flight dynamic effects
    - Configuration 2: drag effects on the body and rotors
    - Configuration 3: model of turbulence acting on the sUAS
    - Configuration 4: sources of random error between the thrust coefficients of the four rotors
  - Distributed Electric Propulsion (DEP) aircraft (sound IDs 702 to 708).

The Gain column indicates the gain applied to the original sound. See Ref. [7] for additional descriptions of the stimuli. The intended SELA value from the single channel WAV file of each stimulus is given in the SELA column. The Test Session column indicates if a sound appears in the

Familiarization Session (F), Practice Session (P), Main Test (M), or two of the sessions. Note that sound ID 101 is a duplicate of sound IDs 151 and 161, but it also appears in the Familiarization Session. In the Height column, AGL means Above Ground Level.

Table A 1. Feasibility Test sounds.

| ID Number | Vehicle | Configuration | Height (m AGL) | Speed (m/s) | Sound Length (s) | Gain Applied | SELA (dB) | Test Session | | ID Number | Vehicle | Configuration | Height (m AGL) | Speed (m/s) | Sound Length (s) | Gain Applied | SELA (dB) | Test Session |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | SUI | OEM-2 | 20 | 5 | 29 | 0 | 71.9 | P | | 289 | Phantom 2 | OEM | 20 | 10 | 19 | 0 | 64.5 | M |
| 54 | SUI | OEM-2 | 20 | 5 | 31 | 0 | 71.5 | F | | 387 | Phantom 2 | OEM | 20 | 5 | 21 | -8 | 57.4 | M |
| 101 | SUI | OEM-2 | 20 | 5 | 29 | 0 | 73.4 | M, F | | 296 | VPV | - | 10 | 5 | 18 | 0 | 69.2 | M, F |
| 151, 161 | SUI | OEM-2 | 20 | 5 | 29 | 0 | 73.4 | M | | 299 | VPV | - | 30 | 5 | 22 | 0 | 64.6 | M |
| 102 | SUI | OEM-2 | 20 | 5 | 30 | 0 | 72.5 | M | | 300 | VPV | - | 10 | 5 | 18 | 0 | 66.1 | M |
| 105 | SUI | OEM-3 | 30 | 5 | 38 | 0 | 72.3 | M | | 306 | VPV | - | 10 | 10 | 17 | 0 | 62.5 | M |
| 110 | SUI | OEM-3 | 20 | 10 | 15 | 0 | 69.4 | M | | 308 | VPV | - | 10 | 10 | 14 | 0 | 61.2 | M |
| 113 | SUI | OEM-3 | 30 | 10 | 21 | 0 | 68.0 | M, F | | 404 | Subaru | - | 10 | 10 | 16 | 0 | 61.7 | M |
| 117 | SUI | OEM-3 | 50 | 5 | 33 | 0 | 70.7 | M | | 407 | Subaru | - | 10 | 10 | 22 | 0 | 62.3 | M |
| 120 | SUI | OEM-3 | 100 | 5 | 52 | 0 | 68.1 | M | | 408 | Subaru | - | 10 | 10 | 22 | 0 | 61.8 | M |
| 124 | SUI | OEM-3 | 20 | 5 | 26 | 0 | 72.4 | M, P | | 457 | Subaru | - | 10 | 10 | 22 | 12 | 74.3 | M |
| 130 | SUI | OEM-3 | 30 | 5 | 26 | 0 | 70.5 | M | | 458 | Subaru | - | 10 | 10 | 22 | 6 | 67.8 | M |
| 132 | SUI | OEM-3 | 50 | 5 | 39 | 0 | 69.7 | M | | 410 | Step Van | - | 10 | 10 | 22 | 0 | 66.4 | M |
| 135 | SUI | OEM-3 | 100 | 5 | 44 | 0 | 65.9 | M | | 415 | Step Van | - | 10 | 10 | 22 | 0 | 66.6 | M |
| 204 | DaX 8 | - | 20 | 5 | 22 | 0 | 80.4 | M | | 417 | Step Van | - | 10 | 10 | 18 | 0 | 66.6 | M, F |
| 207 | DaX 8 | - | 20 | 5 | 24 | -12 | 65.7 | M | | 467 | Step Van | - | 10 | 10 | 18 | 4 | 70.6 | M |
| 212 | DaX 8 | - | 40 | 5 | 32 | 0 | 76.5 | M | | 418 | Box Truck | - | 10 | 10 | 21 | 0 | 77.0 | M |
| 213 | DaX 8 | - | 40 | 5 | 34 | -12 | 65.3 | M | | 422 | Box Truck | - | 10 | 10 | 17 | -5 | 72.5 | M, F |
| 220 | DaX 8 | - | 55 | 5 | 35 | 0 | 77.1 | M, P | | 423 | Box Truck | - | 10 | 10 | 18 | -10 | 66.8 | M |
| 221 | DaX 8 | - | 55 | 5 | 39 | -12 | 62.8 | M, F | | 472 | Box Truck | - | 10 | 10 | 17 | -15 | 62.5 | M |
| 242 | Phantom 2 | APC | 20 | 10 | 16 | 0 | 63.4 | M | | 473 | Box Truck | - | 10 | 10 | 18 | -20 | 56.8 | M |
| 245 | Phantom 2 | APC | 20 | 5 | 17 | 0 | 62.6 | M | | 424 | Utility Van | - | 10 | 10 | 16 | 0 | 64.9 | M |
| 246 | Phantom 2 | APC | 5 | 5 | 14 | 0 | 69.2 | M | | 426 | Utility Van | - | 10 | 10 | 17 | 0 | 64.6 | M |
| 250 | Phantom 2 | APC | 5 | 10 | 14 | 0 | 68.2 | M, F | | 431 | Utility Van | - | 10 | 10 | 15 | 0 | 65.5 | M |
| 257 | Phantom 2 | APC | 20 | 10 | 12 | -6 | 56.0 | M | | 474 | Utility Van | - | 10 | 10 | 16 | 4 | 68.9 | M, P |
| 262 | Phantom 2 | CF | 10 | 10 | 20 | 0 | 72.3 | M | | 476 | Utility Van | - | 10 | 10 | 17 | -4 | 60.6 | M |
| 264 | Phantom 2 | CF | 5 | 10 | 14 | -8 | 61.0 | M | | 601 to 603 | Quadcopter* | 1 | 6 | 6 | 23 | 21 | 68.7 | M |
| 267 | Phantom 2 | CF | 20 | 5 | 20 | 0 | 66.3 | M | | 611 | Quadcopter* | 2 | 6 | 6 | 23 | 21 | 69.2 | M, F |
| 269 | Phantom 2 | CF | 20 | 10 | 18 | 0 | 66.3 | M | | 621 | Quadcopter* | 3 | 6 | 6 | 23 | 21 | 65.8 | M, P |
| 272 | Phantom 2 | CF | 20 | 10 | 19 | -8 | 59.7 | M | | 631 to 633 | Quadcopter* | 4 | 6 | 6 | 23 | 21 | 66.5 | M |
| 282 | Phantom 2 | OEM | 7 | 5 | 13 | 0 | 69.4 | M | | 702, 703, 705 to 708 | DEP* | - | 300 | 31 | 15 | 14 | 67.3, 64.1, 76.3, 72.0, 61.0, 64.6 | M |
| 382 | Phantom 2 | OEM | 7 | 5 | 13 | -8 | 61.4 | M | | 704 | DEP* | - | 300 | 31 | 15 | 14 | 74.1 | F |
| 287 | Phantom 2 | OEM | 20 | 5 | 21 | 0 | 65.4 | M | | | | | | | | | | |