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Urban Air Mobility Noise Remote Test Response by Geographic Area and Comparison to In- Person Test

Session: Human Response to UAS and UAM Noise

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Abstract This paper discusses results of a remotely administered psychoacoustic test that investigated annoyance to Urban Air Mobility (UAM) vehicle noise. One of the main test results was that test participants residing in areas of low and high noise soundscapes reacted differently to the UAM vehicle noise. Potential reasons for this result are presented via examination of responses to post-test questions. The paper also compares the remote test responses with those from an in-person test that compared conventional lightweight helicopter noise responses to that of noise from a variety of UAM vehicles. A portion of the remote test participant responses produced a span of mean annoyance responses to UAM vehicle noise that was different from that produced by the in-person test participants. Post-test responses are also examined to provide potential reasons for this difference.

Keywords: Psychoacoustics; Urban Air Mobility; Advanced Air Mobility; Remote Testing

1. INTRODUCTION

1.1 Test Introduction and Motivation

In 2025, the National Aeronautics and Space Administration (NASA) conducted the Varied Advanced Air Mobility Noise and Geographic Area Response Difference (VANGARD) psychoacoustic test. This test gathered annoyance responses from residents of New York City, Dallas-Fort Worth, and Los Angeles metropolitan regions to the noise of various passenger and equivalent cargo carrying Advanced Air Mobility/Urban Air Mobility (UAM) vehicles in departure, cruise,¹ and approach flight phases. In this test, an online application played sound files of UAM vehicles to test participants over audio devices on their home or office computers so that the participants could provide their reaction, in the form of an

¹ The cruise phase of flight consists of the UAM vehicle flying at constant altitude and speed. The cruise flight phase may be referred in other documents/communications as an en route flight operation or as a flyover.

annoyance response, to the sounds.

The VANGARD Test was motivated by consensus among the UAM Noise Working Group (UNWG) that community variation in UAM vehicle noise perception needed to be understood. At the time of this consensus, there was limited human response data for UAM vehicle noise. This consensus view was captured by a recommendation in the Human Response and Metrics chapter of the UNWG white paper [1] that “A laboratory test campaign be used to explore differences in perception of UAM vehicle noise between communities, so that future policy decisions are based on data representing a wide range of environments.”

1.2 Comparison with Previous Test on UAM Noise Responses from Different Regions

After this recommendation, a psychoacoustic test on UAM vehicle noise, detailed in Ref. [2], gathered responses from participants in the New York City, Orlando, and San Francisco metropolitan regions. Analyses of test results from Ref. [2] focused on comparing UAM vehicle noise response with that of other aircraft, the impact of background sounds that could interfere with, or mask, UAM vehicle noise, and the impact of aircraft visuals. Analyses results presented both similarities and differences in responses among the metropolitan regions.

Completion of the VANGARD Test further addresses the UNWG white paper recommendation to gather UAM vehicle noise responses from different communities. In contrast with the psychoacoustic test detailed in Ref. [2], the VANGARD Test:

- Used sounds from a larger variety of UAM vehicles but did not use sounds of other types of aircraft.
- Allowed participant responses to be analyzed by postal area instead of just by metropolitan regions.
- Did not investigate the effects of background sounds that could mask UAM vehicle noise.
- Did not compare annoyance to noise from visible versus out-of-sight aircraft operations.

Section 2, provides details of how the VANGARD Test was prepared and conducted.

1.3 VANGARD Test Objectives

There were six main objectives of the VANGARD Test that are described in Ref. [3]. Section 3 of this paper is devoted to detailed analysis of two of the main test objectives:

- 1. Are annoyance responses to UAM vehicle noise different between test participants who reside in low versus high noise postal areas?*
- 2. How does noise sensitivity, as measured from a post-test questionnaire, contribute to explaining the annoyance response to UAM vehicle noise?*

While the VANGARD Test included UAM vehicle sounds in cruise flight, it placed an emphasis on understanding the response to departure and approach flight conditions. It was hypothesized that UAM vehicle noise would be less annoying during the cruise phase of flight compared to other types of aircraft noise, such as that of conventional helicopters, flying similar flight paths. It was less clear how the noise from departure and approach phases of UAM vehicle flight would be perceived. An implication of this emphasis on departure and approach flight conditions is discussed in Section 2.3.

To provide additional insight into results associated with the main test objectives, other pre-planned data analyses were investigating biases in the distributions of computer volume levels, metropolitan regions, and the sequences in which test stimuli were presented to

VANGARD Test participants. These factors were associated with responses to the UAM vehicle sounds.

1.4 Comparison with UAM Noise Responses Gathered in a Controlled Facility

NASA conducted another psychoacoustic test on UAM vehicle noise response in 2025, called the Helicopter and UAM Laboratory Comparison (HULC) Test [4]. The HULC Test investigated human response differences between that of conventional lightweight helicopter noise and UAM vehicle noise. Unlike the VANGARD Test, the HULC Test did not have participants from geographically distinct metropolitan regions. Importantly, many UAM vehicle sounds were shared between the HULC and VANGARD Tests. The HULC Test was conducted in the Exterior Effects Room (EER) [5] at NASA's Langley Research Center with 40 participants from the Hampton Roads, Virginia, region. The EER is a psychoacoustic testing facility that offers test administrators greater control of test stimuli than an online test taken at a participant's home or office. Section 3 compares annoyance responses to the UAM vehicle sounds from the HULC and VANGARD Tests.

2. METHODOLOGY

Preparations for the VANGARD Test consisted of five main steps: 1. Generating test sound stimuli (Section 2.1), 2. Preparing the online test application and test questions (Sections 2.2 to 2.4), 3. Selecting geographic locations for participant recruitment (Sections 2.5 and 2.6), 4. Obtaining test approvals (Section 2.7), and 5. Recruiting participants (Section 2.8). These preparations were followed by test execution (Section 2.9).

2.1 Test Sound Stimuli

In the VANGARD Test, single-event flyover sounds of UAM vehicles were presented to participants. Details of the sounds are briefly summarized in this paper; Ref. [3] provides more information on the sounds and how they were generated. Each event was the sound of a single UAM vehicle in a departure, cruise, or approach flight condition. Some sounds were based on recordings of UAM vehicles, but others were auralizations derived from aerodynamic simulations and acoustics prediction codes. There were 67 unique UAM vehicle sounds in the VANGARD Test, with 28 sounds representing departure flights, 12 sounds representing cruise flights, and 27 sounds representing approach flights. The durations of the sounds varied between 13 and 45 seconds, and the average was 25 seconds. The maximum A-weighted sound pressure level, $L_{A,max}$, of the sounds varied between 39 and 76 dB, with an average $L_{A,max}$ of 59 dB. As a result, the A-weighted sound exposure level, L_{AE} , of each sound was different. To help test response consistency, three of the 28 departure sounds were each repeated two more times and gave a total of 73 test stimuli.

UAM vehicle sounds were binauralized for headphone presentation. When listening with headphones, each UAM vehicle sound gave the impression that it was moving from left to right or right to left. The binauralization process is described further in Ref. [3].

Original Equipment Manufacturers (OEMs) provided NASA with data to generate many of the UAM vehicle sounds. As part of agreements between NASA and the OEMs, the make/model of UAM vehicle corresponding to each sound would not be revealed to test participants or the public. Similarly, the pressure time histories of the sounds will not be released. There were no visualizations of the UAM vehicles in the VANGARD Test.

A low-level background sound, described in Ref. [3] as being approximately red/brown noise, was played along with the UAM vehicle sounds in the VANGARD Test. This background sound was not at levels that masked the UAM vehicle sounds. It had two purposes. One

purpose was to mask extraneous sounds, like bird chirps, that may have been present in sound stimuli that were based on recordings. The other purpose was to provide a common baseline for a quiet environment. For participants who take the test in environments that vary in quietness, the low-level background sound provided a common dynamic range of sound levels between instances with and without the presence of test vehicle stimuli. Test participants were informed of the low-level background sound, and the same background sound was presented to all participants.

2.2 Remote Psychoacoustic Testing Platform

NASA utilized its Remote Psychoacoustic Testing Platform to conduct the VANGARD Test. This platform allows an aviation-noise psychoacoustic test to be administered online to participants at a home or office location. The location needs to have internet connectivity that allows streaming media speeds of at least 1 Mbps and access to an audio playback device, preferably over-the-ear headphones. Development of the NASA Remote Psychoacoustic Testing Platform is described in Ref. [6], and updates made to the platform for the VANGARD Test are described in Ref. [3].

Figure 1 illustrates how a participant navigated the NASA Remote Psychoacoustic Testing Platform. Additional information on the steps in Figure 1 are given in Refs. [6, 3]. The following details may be pertinent to the reader:

- Before being given access to the test platform, participants were sent, by email, electronic consent and privacy forms to read.
- Only participants with approved email addresses could access the test application.
- Participants could enter the make and model of the audio device they were using, but audio devices were not analyzed in this paper.
- Following manual audio calibration described in Refs. [6, 3], participants entered their computer volume into the test application, and volume levels were associated with test responses.
- All Test participants were given the same Familiarization and Practice Session sounds.
- The test application provided test administrator contact information for help with navigating the test or for technical assistance.

The Main Test Session, described in Section 2.3, was followed by the Post-Test Survey, which is described in Section 2.4.

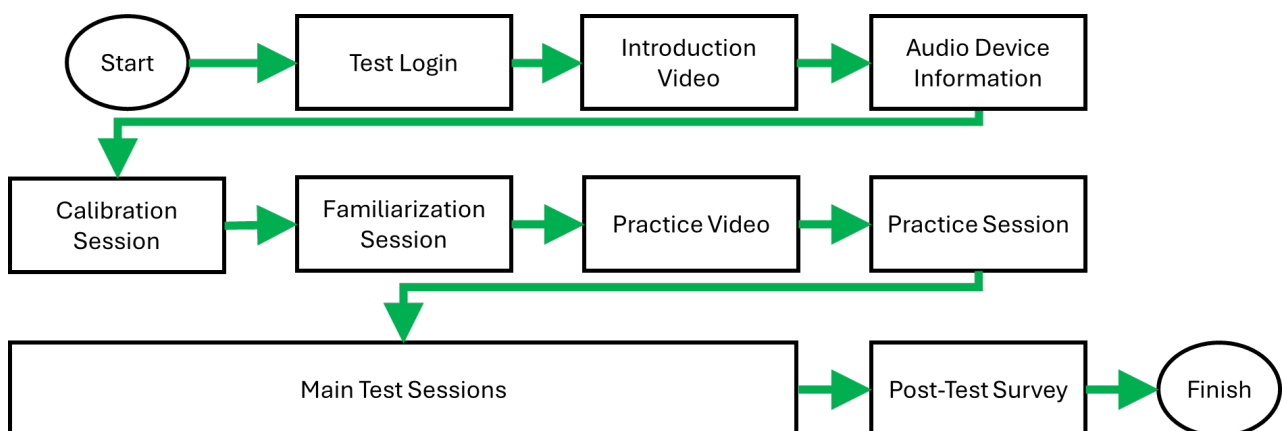


Figure 1: Flowchart of how participants navigated the NASA Remote Psychoacoustic Testing Platform.

2.3 The Main Test

The VANGARD Main Test consisted of participants responding to each single-event UAM

vehicle sound one at a time. After a sound played, the test application provided the prompt in Figure 2. Participants responded to each UAM vehicle sound stimulus using the rating scale of 0-10 specified in Ref. [7], where a rating of “0” indicated “not at all annoyed” by the sound and a rating of “10” indicated “extremely annoyed” by the sound. The question shown in the Figure 2 was used in the VANGARD Test to match the question used in a previous psychoacoustic test that used the NASA Remote Psychoacoustic Testing Platform [6]. After a participant provided their annoyance rating for a sound, the test application would play the next UAM vehicle sound.

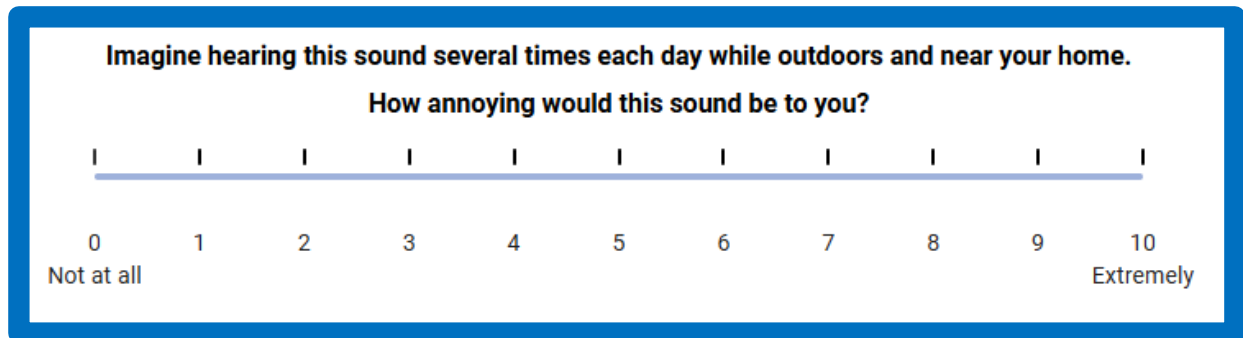


Figure 2. Prompt and rating scale used in the VANGARD Test.

To minimize participant fatigue and the chance of disruptions leading to incomplete tests, the Main Test duration had to be limited to approximately 30 minutes. To meet this duration limit, a total of 68 sounds was estimated as the maximum number of test sounds. With 73 total sounds available for the test, five sounds could not be played to Test Participants for there to be 68 sounds. Instead of withdrawing five sounds from the test, it was decided that, out of the 73 total sounds, the 12 UAM vehicle cruise sounds would be divided among the participants. A participant would hear a random combination of seven of the 12 UAM vehicle cruise sounds that were not heard by other VANGARD Test participants.² With the emphasis, described in Section 1.3, to acquire departure and approach UAM vehicle noise response, it was acceptable for some cruise sounds to not be heard. Note that all participants would still hear the three test sounds that were each repeated two more times because these three sounds represented departure flight phases (see Section 2.1).

The 68 sounds that were played to a participant were divided over five sessions. There were two sessions with 13 sounds and three sessions with 14 sounds. After each session, the test application offered participants the opportunity to take a break and step away from the test. At any time during the Main Test, participants could exit and restart the test from the last sound they were responding to. Participants still needed to complete the VANGARD Test within the days allotted, which are described in Section 2.9.

The sequence by which VANGARD Test sounds were played to participants was not the same for all participants. Ten different stimuli sequences were made using Latin Square ordering [8] as described in Refs. [3, 4]. Reference [3] also describes how the 12 UAM vehicle cruise sounds were distributed over these 10 stimuli sequences. Each VANGARD Test participant was assigned one of the 10 stimuli sequences.

2.4 Post-Test Survey

The post-test questions aimed to gauge a participant’s noise sensitivity and are listed in Ref.

² While 73 is just five more than 68, having between 60 and 64 sounds in the VANGARD was originally preferred. Having 68 sounds was a compromise to minimize the number of sounds to divide among test participants. Meeting a 30-minute time limit for the Main Test was seen as critical to test design, and providing participants with all 73 sounds was seen as being infeasible.

[3]. The first post-test question asked a participant if they changed their computer volume during testing. The remaining post-test questions can be divided into two sets. The first set consisted of Questions 2-6, which are noise sensitivity questions unique to the VANGARD Test and do not appear in other literature. Participants were asked to provide one of five numerical ratings as their response to each question, but Question 6 was a “Yes/No” question. The second set consisted of Questions 7-27, which were noise sensitivity questions from the Weinstein Noise Sensitivity Scale [9]. Each Weinstein Noise Sensitivity question was in the form of a statement, and a participant had to select one of five numerical ratings, with a rating of “1” indicating they agreed strongly and a rating of “5” indicating they disagreed strongly with the statement. Summing the numerical ratings over all 21 Weinstein Noise Sensitivity questions gave a Weinstein Noise Sensitivity Score for each participant.³ Weinstein Noise Sensitivity scores that were higher indicated increased noise sensitivity.

2.5 Selecting Geographic Regions

Metropolitan regions that are likely to be amongst the first to experience UAM operations were selected for this study. Based on Refs. [10, 11, 12], New York City, Dallas-Fort Worth, and Los Angeles were chosen because of their geographical and climatic diversity. Also, each of these large metropolitan regions has a range of persistent noise levels and population densities.

2.6 Selecting Noise Postal Areas

Separating participants by the long-term, or persistent, noise level in their area helped achieve the test objective of analyzing responses from participants in high and low noise postal areas (see Section 1.3). Persistent noise level was measured using the L_{50} metric. The L_{50} value is the A-weighted sound pressure level, L_A , exceeded 50% of the time in an area. The United States National Park Service provides an L_{50} value for each postal code, or ZIP code, in the United States [13]. VANGARD Test participants were asked to self-report their ZIP Code but were not asked to provide their full address. If the L_{50} value for a participant’s ZIP Code was 50 dBA or above, then the participant would be categorized as being in a High Noise Postal Area. Otherwise, they were categorized as being in a Low Noise Postal Area.

Each metropolitan region can be divided into Low and High Noise Postal Areas based on the ZIP Codes in the area. The distribution of Low and High Noise Postal Areas in the three metropolitan regions is shown in magnified maps in Figure 3. High Noise Postal Areas are concentrated in the centers of each region. Figure 3 does not just represent ZIP Codes self-reported by Test participants.

³ The Weinstein Noise Sensitivity Scale normally uses six numerical ratings, but five numerical ratings were used for the VANGARD Test to satisfy information collection requirements by the United States Office of Management and Budget. A response of “5,” which means “disagree strongly,” indicated increased noise sensitivity for some of the Weinstein Noise Sensitivity Scale questions/statements, but for other questions/statements, it indicated reduced noise sensitivity. When summing the Weinstein Noise Sensitivity Scale responses for a participant, for questions/statements where a response of “5” indicated reduced noise sensitivity, responses were summed in reverse. This meant that for these questions/statements, the accumulating score would be “1” for a response of “5” and be “5” for a response of “1.”

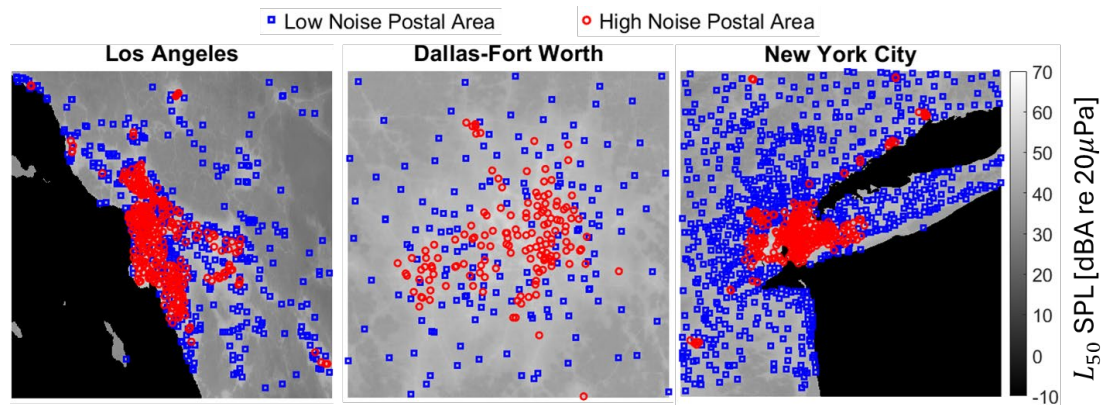


Figure 3: Distribution of Low and High Noise Postal Areas in VANGARD Test metropolitan regions.

2.7 Test Approvals

Multiple approvals were needed for the VANGARD Test. The NASA Institutional Review Board approved that the VANGARD Test, with Federalwide Assurance number 00019876, meets regulations regarding human subjects research. With Privacy Threshold Analysis 3406615 and Privacy Impact Assessment 4146570, NASA approved that the VANGARD Test online application protects participant Personally Identifiable Information (PII). The United States Office of Management and Budget (OMB) approved the VANGARD Test's information collection from public participants after a review of the test's objectives, recruitment methods, and analyses methods. The OMB provided Control Number 2700-0196 for its approval.

2.8 Participant Recruitment

Floor23 Digital LLC (Floor23) assisted NASA in recruiting participants for the VANGARD Test. Recruitment began approximately five weeks before the VANGARD Test was to be administered. Floor23 restricted outreach to legal residents of the United States who were 18 years of age or older and who resided in the New York City, Dallas-Fort Worth, and Los Angeles metropolitan regions. Participants were also required to have computer and internet access and audio equipment, with over-the-ear headphones preferred. Floor23 advertised the VANGARD Test through social and networking platforms. Digital employment platforms were also used for recruitment. They produced the largest number of interested participants over all the digital recruitment channels. Participants were compensated \$25 if they fully completed the VANGARD Test.

In the advertisements to potential participants, the VANGARD Test was referred to as "NASA's Future Aircraft Sound Study." Advertisements did not mention UAM vehicles/operations or identify the specific aircraft that participants would hear.

2.9 Conducting the Test

The VANGARD Test was conducted from August 27, 2025, to September 30, 2025. Participants were not given this entire date range to complete the test. Instead, there were four "Rounds" of participants, with participants in each Round given the range of dates, shown in Table 1, to complete the test. From Table 1, note that some time was needed after a Round to prepare for the next Round of participants. Participants in a Round who did not fully complete the VANGARD Test would not be allowed to continue testing and would not be monetarily compensated.⁴ After the VANGARD Test began with Round 1 participants, Floor23 continued recruiting participants for the remaining Rounds. Floor23 was available

⁴ If a participant in a Round could not continue testing due to technical difficulties, they would be allowed to test in another Round.

by phone and email to assist test participants during normal business hours. Floor23 coordinated with NASA to address participants' technical issues.

Table 1: Dates for each Round of VANGARD Test Participants.

Round Number	Test Dates in Year 2025	Number of Days
1	August 27 – September 3	8
2	September 8 – September 15	8
3	September 17 – September 19	3
4	September 22 – September 30	9

Floor23 attempted to maintain an approximately equal balance between Low and High Noise Postal Area participants because analyzing response differences between these two Noise Postal Areas was a primary test objective. Obtaining an equal balance was challenging. Interest in the VANGARD Test was high from people in High Noise Postal Areas over all three metropolitan regions. For Rounds 1 and 2, 1,085 people from High Noise Postal Areas expressed interest in taking the VANGARD Test, while 279 people from Low Noise Postal Areas expressed interest in the test for these first two rounds.⁵ Based on 2010 population data from the United States Census Bureau, approximately 35 million people lived in the Low Noise Postal Areas over all three metropolitan regions, and approximately 31 million people lived in the High Noise Postal Areas [14].⁶ The higher number of people from High Noise Postal Areas, 1,085, who showed interest in the VANGARD Test appears to not be a result of higher populations in those areas. For Rounds 3 and 4, Floor23 focused recruitment efforts in Low Noise Postal Areas, and there was a pause in recruiting from digital employment platforms that were predominantly producing High Noise Postal Area volunteers.

Table 2 shows how many volunteers from each Noise Postal Area were given access to the VANGARD Test over all four Rounds. The table does not indicate how many people fully completed the test. High Noise Postal Area participants are the majority in each round. Many High Noise Postal Area volunteers who expressed interest in participating could not be given access to the VANGARD Test.

Table 2: Number of VANGARD Test volunteers given access to the test in each Round and from ZIP Codes categorized as Low or High Noise Postal Areas.

Noise Postal Area	Round 1	Round 2	Round 3	Round 4	Total
Low	188	82	11	39	320
High	225	97	36	114	472
Both	413	179	47	153	792

Out of the 792 total number of participants, indicated by Table 2, 359 participants over all four Rounds and all three metropolitan regions fully completed the VANGARD Test. Six participants indicated that they changed their computer volume after manual calibration and were not included in the analyses. After excluding those six participants, 151 participants

⁵ These numbers of High and Low Noise Postal Area volunteers were from initial interest. Some volunteers in both Noise Postal Areas were excluded from participating because they did not respond to follow-up invites or did not meet other testing requirements like having proper audio equipment.

⁶ Populations were estimated over all ZIP Codes in the New York City, Dallas-Fort Worth, and Los Angeles metropolitan regions targeted by recruitment and outreach and not just the ZIP Codes of the participants who expressed interest. When estimating populations from the United States Census Bureau data, populations for 10% of the Low Noise Postal Area ZIP Codes and 35% of the High Noise Postal Area ZIP Codes could not be directly found. For these ZIP Codes where population data were missing, their populations were estimated using the populations of the nearest ZIP Codes for which population data were available.

were from Low Noise Postal Areas and 202 were from High Noise Postal Areas. When Low and High Noise Postal Area participants are referred to in the remainder of this paper, the reference is for those participants who fully completed testing and indicated that they did not change their computer volume after calibration.

Figure 4 shows the distribution of these 353 Test Participants by metropolitan region and noise level, which is based on the L_{50} value corresponding to their ZIP Codes. The High Noise Postal Area Participants, with L_{50} values at least 50 dBA, have a 10 dB span in persistent noise level. Most of the Low Noise Postal Area Participants have L_{50} values that range from 45 to 50 dBA with only some participants being in ZIP Codes with L_{50} values below 45 dBA. Most participants in both the Low and High Noise Postal Areas reside in the New York City metropolitan region.

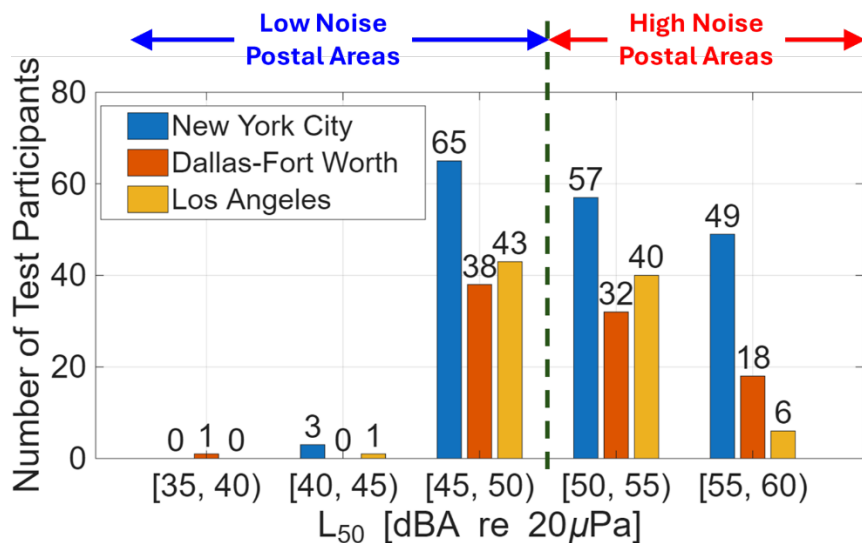


Figure 4: Distribution of VANGARD Test Participants by metropolitan region and noise level.

Participants were requested to provide their age range and whether they were male/female. While all participants confirmed to being at least 18 years of age before being given access to the VANGARD Test, only 246 of the 359 participants who fully completed the Test provided their age and whether they were male/female. Figure 5 shows the age and male/female distributions of these participants. The “NA” in Figure 5 is for the percentage of participants who did not provide their age or whether they were male/female. Assuming the distributions were similar among the participants in the “NA” category, the demographic data suggests that most participants were between 25-34 years of age and male.

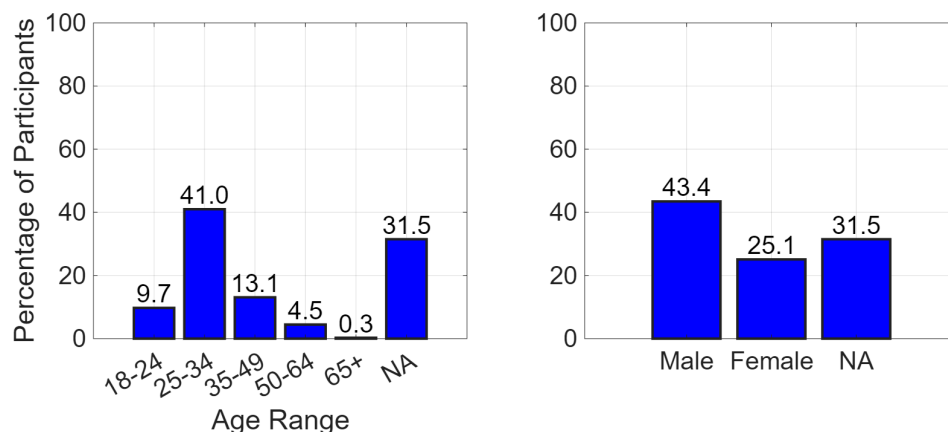


Figure 5: Age Range and Male/Female distributions of participants who fully completed the VANGARD Test.

2.10 The HULC Test

Details of the HULC Test are given in Ref. [4]. The HULC test compared annoyance to conventional lightweight helicopter noise and UAM vehicle noise (see Section 1.4). While many UAM vehicle sounds were shared between the VANGARD and HULC Tests, some UAM vehicle sounds that were played in one test but not the other. The 40 HULC Test Participants from the Hampton Roads, Virginia, region needed to appear in-person at the EER [5], which is a psychoacoustic testing facility that offers greater audio control of test stimuli than an online test. The same annoyance response question used in the VANGARD Test, shown in Figure 2, was asked to HULC Test participants.

3. RESULTS AND DISCUSSION

3.1 Response Differences between Low and High Noise Postal Area Participants

Figure 6 shows VANGARD Test results to answer the question:

Are annoyance responses to UAM vehicle noise different between test participants who reside in low versus high noise postal areas?

The results indicate that High Noise Postal Area participants, over all three metropolitan regions, were more annoyed, on average, by the UAM vehicle sounds than Low Noise Postal Area participants. In Figure 6, the mean responses to the 73 VANGARD Test stimuli are plotted as a function of L_{AE} . Each marker in the Figure 6 graph is the mean response rating to a stimulus at that stimulus's L_{AE} value. The blue square markers represent the mean response to the stimulus over all 151 Low Noise Postal Area participants and over all three metropolitan regions. The red circle markers represent the mean response to the stimulus over all 202 High Noise Postal Area participants and over all three metropolitan regions. A categorical linear regression was performed on the mean responses to produce two fit lines that were forced to have the same slope: one for the Low Noise Postal Area participant responses and the other for the High Noise Postal Area participant responses.⁷ The coefficient of determination, R^2 , of the categorical linear regression was 0.82, which indicates a good fit to the data. The L_{AE} offset between the Low and High Noise Postal Area fit lines is 8.6 dB and the vertical offset is 0.79 annoyance ratings, which is given in Table 3. With these offsets, the L_{AE} of a UAM vehicle flyover will need to decrease by 8.6 dB for the mean annoyance of High Noise Postal Area participants to decrease by 0.79 annoyance ratings and match the value of the Low Noise Postal Area participants. Bootstrapped regressions, following the method described in Ref. [15], generated a 95% confidence interval of [7.7, 9.7] dB for the L_{AE} offset between the Low and High Noise Postal Area fit lines and, as given in Table 3, generated a 95% confidence interval of [0.75, 0.83] annoyance ratings for the mean annoyance rating offset. These confidence intervals do not overlap with 0 dB, indicating that they are statistically significant.

Table 3 also gives categorical linear regression results when Low and High Noise Postal Area participant responses are considered within each metropolitan region. Response differences are still detected between Low and High Noise Postal Area participants within each metropolitan region. Good fits to the data are still indicated when considering participants in each region, although the R^2 values are slightly lower compared with

⁷ Separate linear regressions of L_{AE} and the Low and High Noise Postal Area Participant responses produced slopes of 0.093 and 0.089 annoyance ratings per dB for Low and High Noise Postal Area Participants, respectively. The forced slope of 0.091 annoyance ratings per dB in Figure 6 was used so that an offset between the fit lines can be defined at any value of L_{AE} . When analyzing responses from individual metropolitan areas, the forced slopes were 0.093, 0.082, and 0.099 for the New York City, Dallas-Fort Worth, and Los Angeles metropolitan regions, respectively.

considering participants over all three regions. Offset confidence intervals overlap between participants in the New York City and Dallas-Fort Worth metropolitan regions, indicating that the difference between Low and High Noise Postal Area participant responses are similar in these two metropolitan regions. Low and High Noise Postal Area participant responses are closer in the Los Angeles metropolitan region.⁸

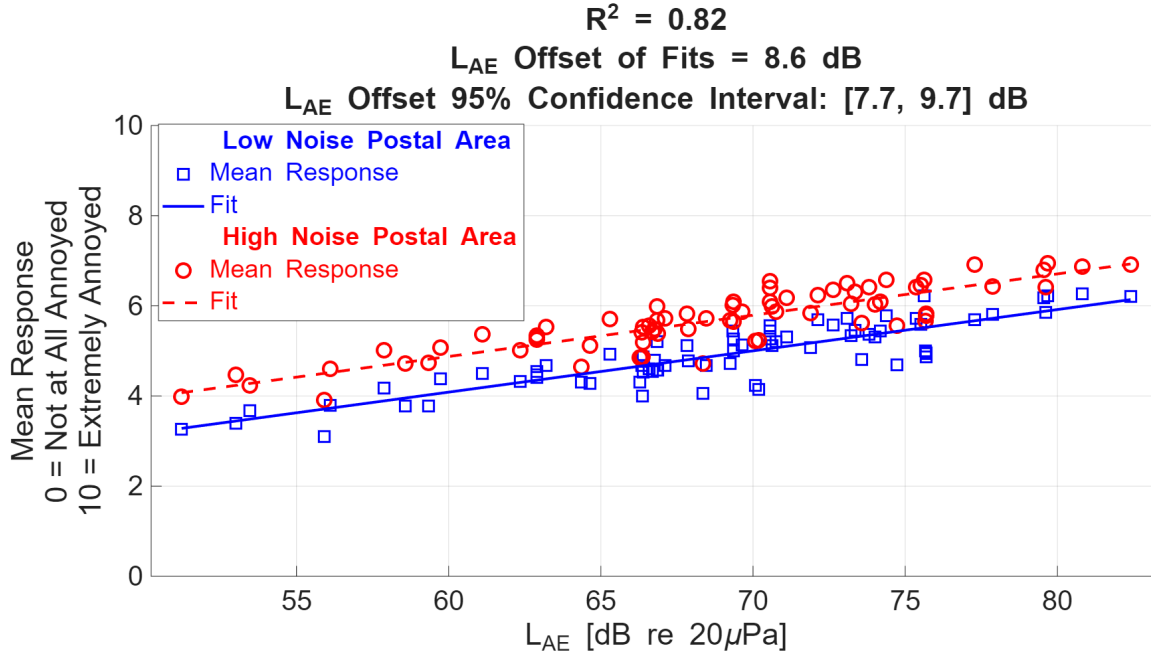


Figure 6: VANGARD Test results showing mean annoyance response difference between Low and High Noise Postal Area participants.

Table 3: Categorical Linear Regression R^2 and offset results by metropolitan region of Low or High Noise Postal Area Participant responses and L_{AE} . Offset values are followed by 95% confidence interval in brackets (“[]”).

Metropolitan Region	R^2	L_{AE} Offset	Mean Annoyance Rating Offset
All	0.82	8.6 [7.7, 9.7]	0.79 [0.75, 0.83]
New York City	0.81	9.4 [8.1, 11]	0.87 [0.80, 0.93]
Dallas-Fort Worth	0.76	9.2 [7.1, 11]	0.76 [0.68, 0.83]
Los Angeles	0.72	6.0 [4.9, 7.2]	0.59 [0.51, 0.68]

Results from two previous studies known to the author indicated annoyance response differences between geographically distinct communities. For one of these studies, the Neighborhood Environmental Survey [16], analyses did not produce a compelling explanation of potential factors that may have been contributing to response differences between communities. Response differences between participants in the Eastern and Western United States were also observed in the remote psychoacoustic test described in Ref. [6], but reasons for the differences were not investigated.

For the VANGARD Test, analyzing post-test questions that measure noise sensitivity (see Section 2.4) to explain annoyance responses was a pre-planned test objective (see Section 1.3). As mentioned in Section 2.8, participants were told that the test was on “future aircraft sounds,” and people were reacting to a potentially new noise source. VANGARD Test recruitment witnessed considerably more interest from people in High Noise Postal areas

⁸ While response differences between metropolitan regions were not considered in the analyses in this paper, the total mean annoyance ratings, found by computing the mean over the stimuli mean responses, were 5.38, 5.36, and 5.03 annoyance ratings for participants in the New York City, Dallas Fort-Worth, and Los Angeles metropolitan regions, respectively. The total mean annoyance rating was 5.29 annoyance ratings for participants over all three metropolitan regions.

(see Section 2.8) and a greater number of High Noise Postal Area participants in each Round (see Table 2 of Section 2.9). These facts further incentivize analyses of responses to the post-test questionnaire to determine if differences in noise sensitivity between Low and High Noise Postal Area participants are contributing to the results in Figure 6 and Table 3.

The mean responses to each of the first set of noise sensitivity questions, Post-Test Questions 2-6, were found over the participants in each Noise Postal Area. The 95% confidence interval for the mean responses were computed through the bootstrapping procedure using resampling with replacement. For all five questions, the Low and High Noise Postal Area participant mean responses had overlapping confidence intervals. A statistically significant difference in mean response between Low and High Noise Postal Area participants was not observed for these five Post-Test Survey noise questions.

Low and High Noise Postal Area participant mean responses for Post-Test Questions 2 and 3 had the least confidence interval overlap, and they are given in Table 4. Post-Test Question 2 was:

On a scale of 1 to 5, with 1 being least sensitive, and 5 being most sensitive, how would you rate your personal reaction to outdoor noise of all types?

High Noise Postal Area Participants rated themselves, on average, as more sensitive. Post-Test Question 3 was:

On a scale of 1 to 5, with 1 being the quietest, and 5 being the noisiest, how would you rate how noisy the background sound typically is outside of your home during the day?

High Noise Postal Area Participants rated background sounds outside their home, on average, as noisier. The mean ratings were not statistically different from those of Low Noise Area Participants, but the confidence interval overlap was 0.03 sensitivity ratings for Post-Test Question 2 and 0.06 in noisiness for Post-Test Question 3.

Table 4: Mean survey result over Low or High Noise Postal Area Participants followed by 95% confidence interval in brackets (“[]”).

Post-Test Survey Result	Low Noise Postal Area Participants	High Noise Postal Area Participants
Post-Test Question 2, Sensitivity	3.61 [3.45, 3.77]	3.86 [3.74, 3.99]
Post-Test Question 3, Noisiness	3.02 [2.86, 3.18]	3.27 [3.12, 3.41]
Weinstein Noise Sensitivity Score	69.6 [67.5, 72.0]	71.4 [69.5, 73.4]

Table 4 also shows the mean Weinstein Noise Sensitivity Scores over the Low and High Noise Postal Area participants and their corresponding confidence intervals. These scores were computed by summing the responses to the last 21 Post-Test Survey questions, Questions 7-27 (see Section 2.4). High Noise Postal Area participants had, on average, a higher score, which indicates increased noise sensitivity. The increased sensitivity is not statistically different from that of Low Noise Postal Area participants because of the considerable overlap in the confidence intervals of the mean scores. Analyses of responses to each of the Weinstein Noise Sensitivity questions, whose results are not shown, also did not reveal statistically significant differences in the responses for any individual question between that of Low and High Noise Postal Area participants.

Computer volume level, metropolitan region, and stimuli sequence distributions were examined to explain the response difference between Low and High Noise Postal Area

participants. One reason why these factors were associated with test responses was to check for biases in their distributions among test participants (see Section 1.3). For brevity, analyses results are not shown for differences in computer volume level, which were set during calibration (see Section 2.2). Instead, Table 5 summarizes that computer volume did not appear to be biased between Low and High Noise Postal Area participants. Based on the data in Figure 4, the Table 5 summary does not indicate that the distributions of metropolitan regions were different between the Noise Postal Area groups. To understand if bias in sound sequence order (see Section 2.3) may be contributing to the response difference, Table 6 shows the percentages of participants over each Noise Postal Area group that are in each of the 10 different stimulus sequence groups. One possible example of sequence bias would be if sequences 1-3 each had at least 25% of Low Noise Postal Area Participants and sequences 8-10 each had at least 25% of High Noise Postal Area Participants. Bias like this example is not seen in Table 6. The response difference between Low and High Noise Postal Area participants remains unexplained.

Table 5: Summary of analyzing bias in computer volume level, metropolitan region, and stimuli sequences between Low and High Noise Postal Area participant groups.

Potential Distribution Bias	Analyses Results
Different computer volume levels, set during calibration.	No statistically significant difference in mean computer volume levels found between the two participant groups.
Distribution of participants between groups being different for the three metropolitan regions.	The New York City metropolitan region had the largest percentage of participants among both groups. No metropolitan region appears predominantly represented in one group but not the other.
Participants in each group predominantly being given different stimulus sequences than those in the other group.	Stimulus sequences do not appear to be predominant for one group but not the other.

Table 6: Percentages of participants in each Noise Postal Area that are in each stimuli sequence group. Percentage values are rounded.

Sequence Group	1	2	3	4	5	6	7	8	9	10	All
Percentage of Low Noise Postal Area Participants	9%	9%	13%	10%	9%	11%	12%	10%	7%	9%	100%
Percentage of High Noise Postal Area Participants	9%	12%	8%	11%	11%	10%	9%	9%	10%	9%	100%

3.2 Mean Annoyance Response Span Differences between VANGARD and HULC

Mean annoyance responses as a function of L_{AE} for just the UAM vehicle sound stimuli, and not the helicopter sound stimuli, from the HULC test (see Sections 1 and 2.10) are shown in Figure 7. The coefficient of determination, R^2 , and slope of the linear regression fit line are also given and indicate a good fit.⁹ Unlike the mean annoyance responses for the VANGARD Test shown in Figure 6, the HULC Test mean responses range from near 0 to near 9 annoyance ratings. This difference in the mean response range exists for both Low and High Noise Postal Area participants when compared with HULC Test participant responses. The mean annoyance rating at a given value of L_{AE} was not expected to match between the two tests. One reason is that the geographic origin of test participants was different between the HULC and VANGARD Tests. The previous remote psychoacoustic

⁹ HULC Test results were analyzed using logistic regression in Ref. [4]. In this current document, the results are analyzed using linear regression for easier comparison with VANGARD Test results.

test, discussed in Ref. [6], also observed differences between participants in different geographic locations. Another reason is that the sound stimuli were not identical for the two tests. However, the magnitude of the observed difference in the span of mean annoyance ratings between that of the HULC and VANGARD tests was unexpected.

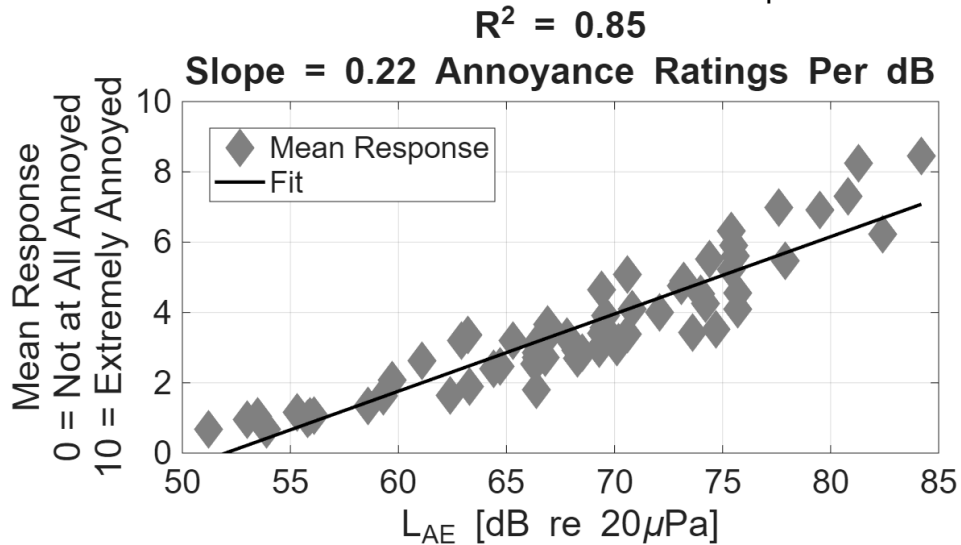


Figure 7: HULC Test mean annoyance responses to UAM vehicle sound stimuli.

As a first step to understanding why this difference in the mean annoyance rating span exists between VANGARD and HULC Test results, it needed to be seen if any VANGARD Test participants gave annoyance response spans like that of HULC Test participants.

For each VANGARD Test participant, a linear regression on their responses against the L_{AE} of each test stimulus yielded values for slope, intercept, and coefficients of determination of the fit line. Since each participant reacted to a stimulus once, the responses were not the mean responses but represented the single reaction that the participant had for each stimulus. Figure 8 gives examples of linear regressions performed on two VANGARD Test participants, Subjects 2 and 4. Subject 2 responded to most test stimuli using ratings of 0, 5, and 10 but provided some ratings between 5 and 10 for a few stimuli. Subject 4 had a smaller slope for the linear regression on their responses but, for each annoyance rating option between 1 and 8, a response was provided at least once.

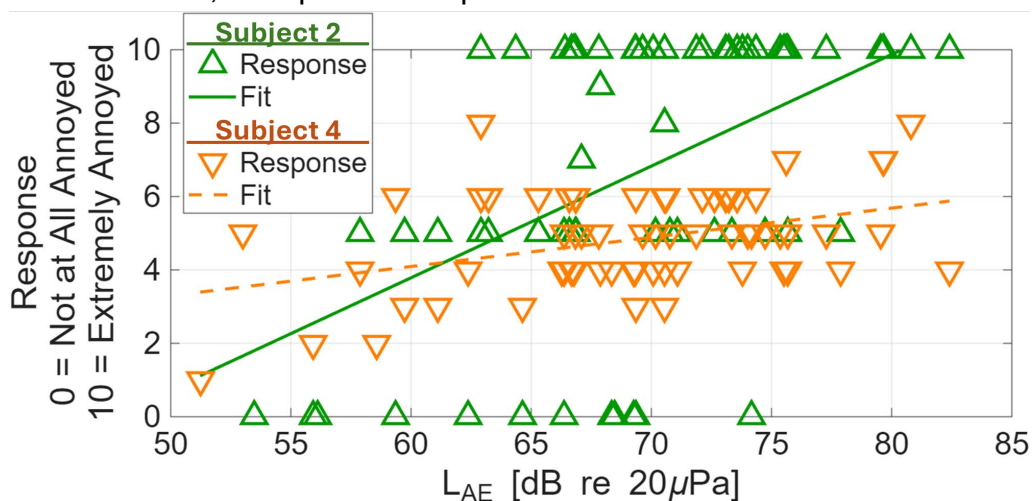


Figure 8: Examples of linear regressions performed on two VANGARD Test participant responses.

Figure 9 gives the distribution of slopes from the linear regressions over all VANGARD Test participants. A total of 243 out of 353 VANGARD Test participants had slopes below 0.12 annoyance ratings per dB. Their distribution is given by the orange bars in Figure 9. These participants are designated as “Small Response-Span” participants. Subject 4 from Figure

8 was a Small Response-Span participant. Some participants had negative slopes, indicating that their annoyance tended to decrease with increasing L_{AE} . These participants are still grouped with the Small Response-Span participants. The remaining 110 VANGARD Test participants had slopes above 0.12 annoyance ratings per dB and are designated as “Large Response-Span” participants. They are represented by the green bars in Figure 9. Subject 2 from Figure 8 was a Large Response-Span participant. The mean slope for Large Response-Span participants was 0.21 annoyance ratings per dB, which is close to the linear regression slope on HULC Test participant mean responses in Figure 7.

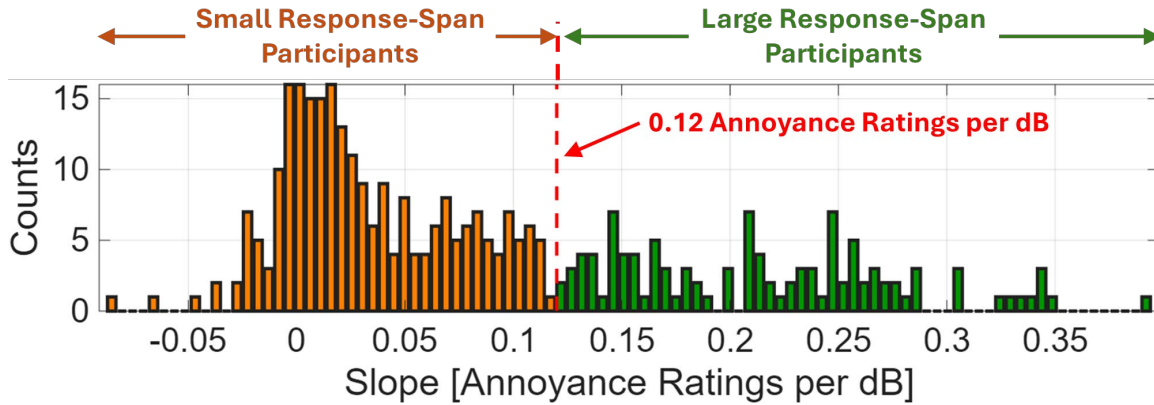


Figure 9: Distribution of VANGARD Test participant linear regression slopes.

Figure 10 shows the mean annoyance responses to VANGARD Test stimuli against L_{AE} for the Small Response-Span participants and again for the Large Response-Span participants. For clarity, the mean responses for both groups are given in separate graphs. HULC Test participant responses from Figure 7 are included for comparison. Each upward pointing green triangle marker is the mean response to each VANGARD Test stimulus over all 110 Large Response-Span participants. Large Response-Span participants collectively gave mean responses like that of HULC Test participants. Mean annoyance rating range for the 243 Small Response-Span participants is from 4.9 to 6.2 annoyance ratings, which gives a span that is slightly larger than a single annoyance rating.

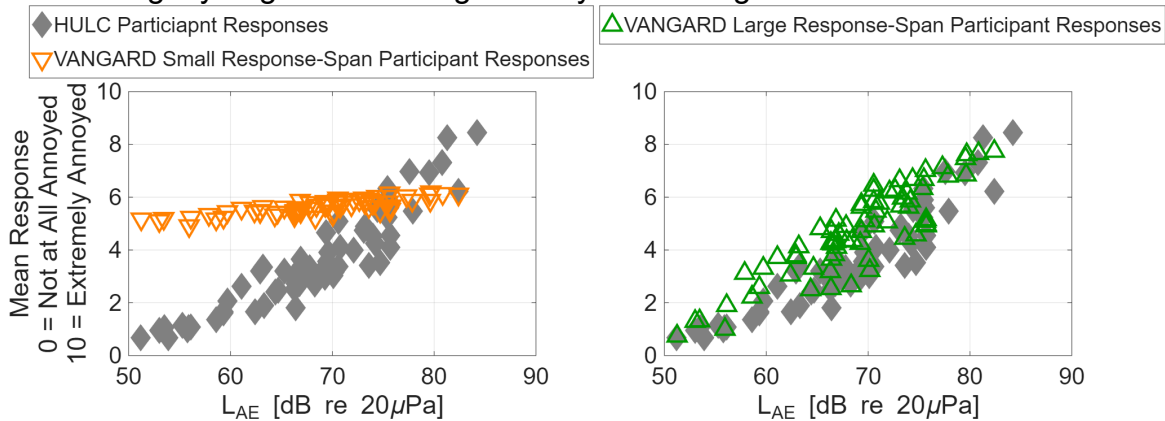


Figure 10: Mean annoyance responses from VANGARD Test Large and Small Response-Span participants.

Although distributions were also found for the intercepts and coefficients of determination of the VANGARD Test participant linear regression fit lines, the distribution of slopes in Figure 9 appear sufficient to categorize participants into the Large and Small Response-Span groups.

Differences in test methodology and recruitment may be a contributor to the mean annoyance response span difference seen in Figure 10. Compared to the VANGARD Test, the HULC Test was administered in a more controlled facility with test administrators offering

in-person guidance to participants. The VANGARD Test relied on manual calibration of audio devices and trust that the test instructions provided online were clear to participants, although participants could contact test administrators for help. Results from the previous online test that used the NASA Remote Psychoacoustic Testing Platform did not appear to show small response spans [6]. However, the recruitment strategy used in the previous test relied on UNWG organizations, and participants were not monetarily compensated, which were different from the recruitment strategy used for the VANGARD Test. This paper attempts to determine if there are other potential contributors to the mean annoyance response span difference.

As was done for the response difference between Low and High Noise Postal Area participants in Section 3.1, responses to the Post-Test Survey were analyzed for evidence of noise sensitivity contributing to the mean annoyance response span difference. Small Response-Span participants formed 73%, 72%, 61%, and 55% of participants in Rounds 1-4, respectively, of the VANGARD Test. These numbers may be indicative of Small Response-Span participants being more eager to provide a reaction to a potentially new noise source, which is a reason for hypothesizing that noise sensitivity is contributing to the mean annoyance span discrepancy.

Statistically significant differences were detected in the mean responses between that of Large and Small Response-Span participants for Post-Test noise sensitivity Questions 2-5. Post-Test Questions 2 and 3 are stated in Section 3.1, but they are summarized here:

- Post-Test Question 2: On a scale of 1-5, rate personal reaction to outdoor noise of all types (1 = least sensitive, 5 = most sensitive).
- Post-Test Question 3: On a scale of 1-5, rate background sound noisiness outside home during the day (1 = quietest, 5 = noisiest).

Post-Test Questions 4 and 5 were:

- Post-Test Question 4: *On a scale of 1 to 5, with 1 being least sensitive, and 5 being most sensitive, how would you rate your personal reaction to aircraft flyovers (helicopters, airplanes: NOT drones) over your home?*
- Post-Test Question 5: *On a scale of 1 to 4, with 1 being least sensitive, and 4 being most sensitive, how would you rate your personal reaction to the sound of drones (unmanned aerial vehicles) that you have experienced? Please answer with "0" if you have never heard a drone in "real life" outdoors.*

As seen in Table 7, to a statistically significant level, Small Response-Span participants reported being more sensitive to outdoor and aircraft noise and having noisier backgrounds outside their homes compared with Large Response-Span participants. For Post-Test Question 5, 13 Small Response-Span and 13 Large Response-Span participants who responded with "0" were excluded from the mean response calculations.

The Weinstein Noise Sensitivity Scores in Table 7 indicate that noise sensitivity is higher for Large Response-Span participants at a statistically significant level. This result appears to contradict the results of analyzing responses to Post-Test Questions 2-5. The Weinstein Noise Sensitivity Scores are formed by summing the responses of Post-Test Questions 7-27. Analyses of responses to the individual Weinstein Noise Sensitivity Post-Test Questions 16 and 24-26, whose results are not shown, revealed, with statistical significance, that they contributed to the Weinstein Noise Sensitivity Score being higher for Large Response-Span participants. Post-Test Question 27 asks participants to respond on a scale of 1-5 to the

statement, “*I am sensitive to noise*,” with “1” being “agree strongly” and “5” being “disagree strongly.” Responses to Post-Test Question 27 had to be summed in reverse to the accumulated Weinstein Noise Sensitivity Score (see Section 2.4). From Table 7, at a statistically significant level, the Small Response-Span participants indicated that they were more sensitive to noise. Analyses of the other 16 Weinstein Noise Sensitivity questions, not shown, did not reveal statistically significant differences between responses of Large and Small Response-Span participants.

Table 7: Mean survey result over Large or Small Response-Span Participants followed by 95% confidence interval in brackets (“[]”).

Post-Test Survey Result	Large Response-Span Participants	Small Response-Span Participants
Post-Test Question 2, Outdoor Noise Sensitivity	3.44 [3.24, 3.64]	3.90 [3.78, 4.01]
Post-Test Question 3, Background Noisiness	2.87 [2.65, 3.10]	3.30 [3.18, 3.42]
Post-Test Question 4, Aircraft Noise Sensitivity	3.51 [3.29, 3.71]	3.82 [3.72, 3.92]
Post-Test Question 5, Drone Noise Sensitivity	2.14 [1.89, 2.35]	2.62 [2.48, 2.74]
Weinstein Noise Sensitivity Score	73.7 [71.3, 75.9]	69.2 [67.3, 71.1]
Post-Test Question 27, Noise Sensitivity (lower rating indicates increased sensitivity)	2.48 [2.28, 2.68]	2.14 [2.00, 2.26]

From these contradictory results, one conclusion is that noise sensitivity question ratings and scores are insufficient to explain the response span differences.

Another hypothesis is that the Large and Small Response-Span participants are each sensitive to the UAM vehicle noise in different ways. From Figure 10, for L_{AE} values above approximately 75 dBA, Large Response-Span participants give higher mean annoyance values to the UAM vehicle sounds. In this higher-valued L_{AE} region, the Large Response-Span participants may be more sensitive to noise and sensitive in different ways than Small Response-Span participants. Most Weinstein Noise Sensitivity questions ask for responses to situations that do not directly involve outdoor or aircraft noise. Examples are Post-Test Question 25, which asks participants about people who make noise, and Post-Test Question 26, which asks participants about being in a home with thin walls. With this context, one hypothesis is that most Weinstein Noise Sensitivity questions, which collectively indicated Large Response-Span participants as being more sensitive, were measuring a sensitivity to noise that was different from the sensitivity measured by Post-Test Questions 2-5 and 27, which indicated that Small Response-Span participants were more sensitive. VANGARD Test’s post-test questions were not designed to test this hypothesis. To provide stronger evidence for it, additional investigations would be needed that focus on testing this hypothesis.

Differences in computer volume level, metropolitan region, and stimulus sequence distributions between Large and Small Response-Span participants were examined. For brevity, analyses results are not shown for these factors, but conclusions match those in Table 5 for Low and High Noise Postal Area participants.

4. CONCLUSION

The VANGARD Test gathered annoyance responses from participants in the New York City, Dallas-Fort Worth, and Los Angeles metropolitan regions to the noise of various passenger and equivalent cargo carrying UAM vehicles. Participants provided their responses through the online NASA Remote Psychoacoustic Testing Platform, which played audio files of the UAM vehicles through the participants’ computers and audio devices. Participants performed manual computer volume level calibrations before taking the VANGARD Test.

This current paper analyzed the results to one of the VANGARD Test's main objectives, which was to investigate if participants in postal areas having low or high long-term, or persistent, noise levels, reacted differently to UAM vehicle noise. **Analysis of VANGARD Test results indicated participants from High Noise Postal Areas being more annoyed by UAM vehicle noise than those from Low Noise Postal Areas.**

Analysis of participant responses to a post-test questionnaire did not provide statistically significant results that pointed to noise sensitivity as a reason for High Noise Postal Area participants being more annoyed. Other factors like computer volume level, metropolitan regions, and sound sequence order also do not appear as contributors to the annoyance response difference. However, High Noise Postal Area participant volunteers showed more interest in VANGARD Test during recruitment. It is not currently clear how much the digital recruitment methods (see Section 2.8), contributed to the response differences.

VANGARD Test results also revealed that 243 participants, referred to as "Small Response-Span" participants, collectively had a relatively small mean annoyance span, approximately 1 annoyance rating. This annoyance span to UAM vehicle noise was much smaller than that produced by participants from another psychoacoustic test, the HULC Test, who responded to both lightweight helicopter noise and UAM vehicle noise. **A total of 111 VANGARD Test participants, referred to as "Large Response-Span" participants, did collectively produce an annoyance span like that of HULC Test participants.**

Analyses of participant responses to a post-test questionnaire found statistically significant differences in noise sensitivity that contradict each other on whether the Large or Small Response-Span participants are more sensitive to UAM vehicle noise. One conclusion is that the post-test questions are insufficient to explain the response span differences. Another hypothesis is that Large and Small Response-Span participants are sensitive to UAM vehicle noise in different ways, but the VANGARD Test's post-test questions were not designed to provide evidence of this hypothesis.

5. FUTURE WORK

Additional analyses may provide insights into VANGARD Test results beyond what was shown in this current paper. There are VANGARD Test data that remain unexplored. As an example, VANGARD Test participants provided details of which audio equipment they used for the test. The audio equipment information was not analyzed in this current paper. Principal component analysis or other machine learning algorithms may be employed on VANGARD Test response data to explore factors contributing to annoyance response differences that have not been considered in this paper. Obtaining VANGARD Test participant ZIP Code characteristics, like L_{90} or other background noise metrics, may allow for additional exploration of test responses. VANGARD Test response data are planned to be released in 2026. When released, other researchers may explore VANGARD Test data to gain insight into test responses.

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