14th ICBEN 2023
18 - 22 JUNE
BELGRADE

14th ICBEN Congress on Noise as a Public Health Problem

Scope and goals of NASA's Quesst Community Test Campaign with the X-59 aircraft

Jonathan Rathsam, Peter Coen, Alexandra Loubeau, Lori Ozoroski, Gautam Shah

NASA Langley Research Center, Hampton, Virginia, USA

Corresponding author's e-mail address: jonathan.rathsam@nasa.gov

ABSTRACT

In its mission to expand knowledge and improve aviation, NASA conducts research to address sonic boom noise, the prime barrier to overland supersonic flight. For half a century, civilian aircraft have been required to fly slower than the speed of sound when over land to prevent sonic boom disturbances to communities under the flight path. However, lower noise levels may be achieved via new aircraft shaping techniques that reduce the merging of shockwaves generated during supersonic flight. As part of its Quesst mission, NASA is building a piloted, experimental aircraft called the X-59 to demonstrate low noise supersonic flight. After initial flight testing to ensure the aircraft performs as designed, NASA will begin a national campaign of supersonic flights over communities to collect data on how people perceive the sounds from this new design. The data collected will support the efforts of national and international noise regulators to develop new standards that would allow supersonic flight over land at low noise levels. This paper provides an update on the planned experimental scope and key goals of the community test campaign.

Keywords: Sonic boom, community survey, dose-response, X-59, annoyance, community test

INTRODUCTION

The United States (US) National Aeronautics and Space Administration (NASA) envisions a future in which faster air travel is available to all. For travelers, faster air travel means more time at destinations and less time traveling. Current regulations that restrict supersonic flight over land[1] are the prime barrier to this vision. When the restrictions went into effect a half century ago, they were intended to prevent sonic boom noise from disturbing communities.

In recent decades the research community has developed new designs for supersonic aircraft that produce a low noise signature instead of a sonic boom, as shown in Figure 1. Simulated low noise signatures are rarely perceived as annoying whether in laboratory tests or field tests. However, low noise signatures from a purpose-built supersonic aircraft have never been tested over a representative population. The community test campaign phase of the NASA Quesst mission will generate these specific data to support the development of supersonic overflight noise certification standards, not based on speed, but on noise level.

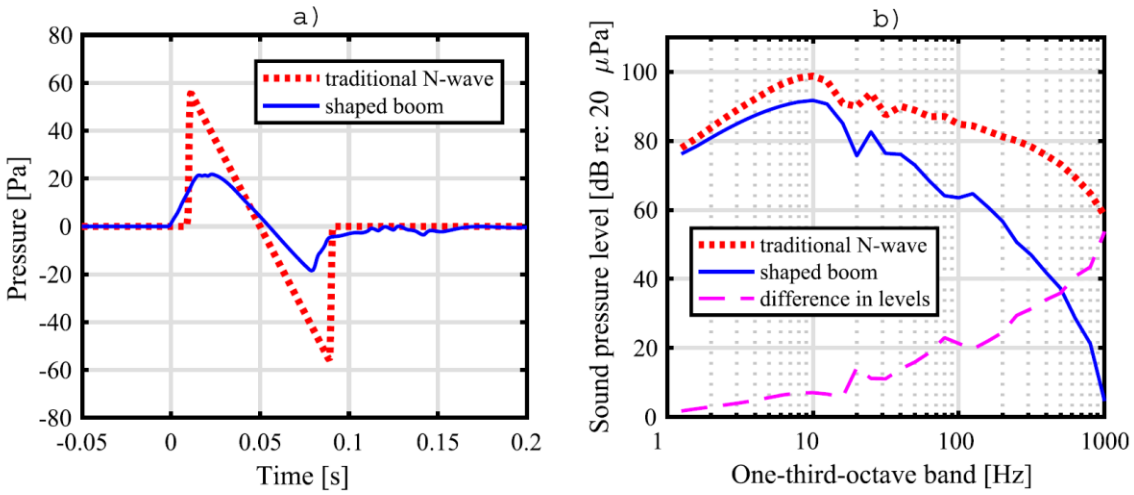

Figure 1: Simulated (a) time histories and (b) one-third-octave band sound pressure levels for a traditional N-wave sonic boom and a low noise signature, or shaped boom.[2]

To put low noise signatures in context with other impulsive sounds, the graphic in Figure 2 shows a range of impulsive environmental sounds arranged by loudness. The scale shown is Perceived Level,[3] an acoustic metric designed for use with impulsive sounds. The NASA X-59 was designed to achieve a low noise supersonic signature of 75 dB, which is equivalent to distant thunder or a car door slam from across the street. This sound is much quieter than the sonic boom from the Concorde at 105 dB, which is equivalent to nearby thunder or a car door slam from inside the car.

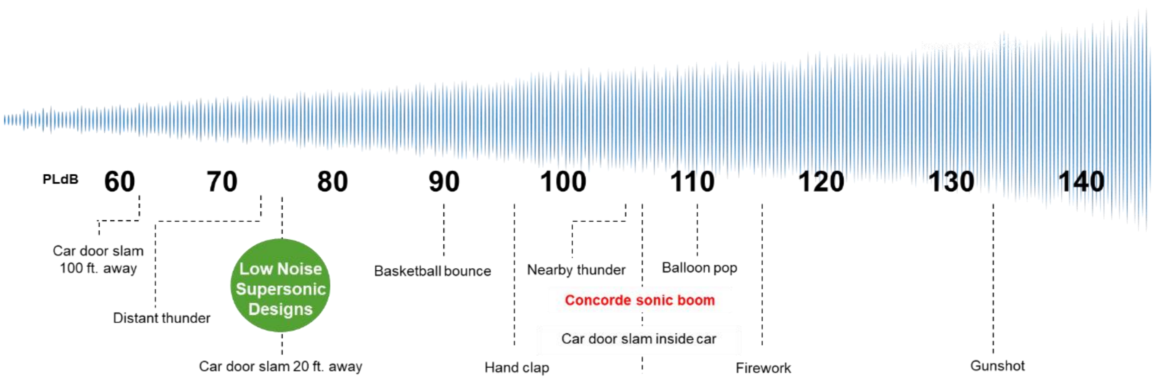

Figure 2: Comparison of Perceived Levels among low noise supersonic designs, Concorde sonic boom, and other impulsive environmental sounds.

RESEARCH GOALS

The primary research goal of the NASA Quesst community test campaign is to collect representative community response data to support the development of supersonic overflight noise certification standards. The data must describe the dose-response relationship between annoyance and noise exposure level. Annoyance is quantified in terms of the standardized five-point verbal annoyance scale[4] subject to a cut-off, or threshold, so the top two response categories represent “highly annoyed.” The noise exposure level is quantified in terms of one of the single-event noise metrics under consideration,[5] such as Perceived Level described above.

A dose-response relationship for single flyover events will directly support efforts to develop a supersonic overflight noise limit, but it does not address the effects of repeated exposure due to multiple overflights within a day. Because future commercial supersonic operations may result in such multiple events, a second dose-response curve is needed for repeated exposures. Again, annoyance is quantified in terms of the standardized five-point verbal annoyance scale[4] subject to a cut-off, or threshold, so the top two response categories represent “highly annoyed.” The noise exposure level is quantified in terms of the cumulative exposure equivalent of one of the single-event noise metrics under consideration.[5]

The secondary research goals of the NASA Quesst community test campaign, listed in order of priority, will aid in interpretation of the dose-response results.

1) Assess the effect of indoor noise-induced rattle sounds and vibration on dose-response relationships. Historic community surveys[6] and laboratory studies[2,7] indicated that noise-induced rattle sounds and vibration are a major contributor to annoyance from conventional sonic booms.

2) Assess the effect of listening environment (home vs. work vs. somewhere else, indoor vs. outdoor, indoor with windows open vs. closed, and urban vs. rural) on dose-response relationships.

3) Assess the effect of time-of-day on dose-response relationships (daytime vs. evening). Survey data collected from both daytime and evening overflights may help inform the formation of an annoyance penalty for evening supersonic overflight noise exposure. Such a penalty may parallel the 5 dB evening penalty (1900 – 2200) in the Community Noise Equivalent Level (CNEL) metric.

4) Assess the prevalence of “startle,” which was a major component of annoyance in historic sonic boom community surveys.[6]

SCOPE OF DATA COLLECTION

This section summarizes the scope of data planned for collection, as well as the data considered out of scope.

Test Locations

To collect nationally representative dose-response data, NASA will conduct community tests at four to six sites representing different geographic regions of the US. The sites will also differ in terms of racial/ethnic composition and levels of urbanicity. The geographic diversity across test sites is intended to capture potential regional differences in public perceptions, as well as regional differences in building structures that may affect outdoor-to-indoor sound transmission. Race/ethnicity is not expected to influence the dose-response relationship, but it is critical to representative results. Different levels of urbanicity, or its correlate population density, will capture potential differences in perceptions among urban, suburban, and rural populations, which could result from differences in ambient noise levels or other factors.

As of the writing of this manuscript, the community test sites are still under consideration.

Noise exposure range

For each community test, NASA anticipates conducting up to 6 supersonic overflights (single events) per day, totaling an estimated 100 such events per test over a month. This number of overflights and month-long test duration have been chosen to give survey participants time to adapt to the new sounds. The PL range being used for noise exposure planning is between 70 and 87 dB, based on current estimates[8] of the levels achievable by the X-59. The single event range corresponds to a cumulative range of approximately 24 to 45 dB in Day-Night-Average Perceived Level, PLDNL. Exposure schedules are being designed to ensure that single event levels are distributed with intention across the PL range. As information on actual acoustic levels from the X-59 becomes available during the initial flight test phase (and prior to community testing), the range for exposure planning will be adjusted to correspond to the X-59 capabilities. While survey participants may be indoors or outdoors during the overflights, out of practicality noise exposure will be estimated outdoors only. The prevalence of rattle and vibration will be addressed via survey questions.

Number of survey participants

For each community test, NASA intends to acquire survey responses from a probability-based sample of at least 1000 participants. This minimum sample size was selected to improve the stability of estimates of simulated dose-response relationships based on survey data from a previous test.[9]

This minimum sample size will also enable representativeness, including diversity of age and socioeconomic status. While neither age nor socioeconomic status is expected to have a strong influence on the dose-response relationship, a representative range is needed for both.

A test of the survey process without X-59 overflights is planned for late 2023. The key goals of the survey test are to demonstrate the recruitment process and web-based survey instrument and to estimate response rates. The minimum sample size of 1000 participants may be adjusted pending results of this survey test, and may also be adjusted for later community tests based on outcomes from early tests.

Data not collected

The effects of nighttime supersonic overflight noise exposure, including possible sleep disturbance, will not be tested in the current timeframe due to a combination of operational and safety considerations. However, overflights in the evening hours after sunset may occur in some community tests.

Community response to focus booms created when the X-59 accelerates into supersonic flight will not be acquired. Focus booms occur over a very limited geographic area making it difficult to accurately predict the location or measure the noise exposure from these events. However, under the assumption that noise annoyance is related to noise exposure level regardless of the specific flight phase when the signature was generated, the dose-response relationships across the noise exposure range derived from steady level flights of the X-59 will be valid for all supersonic flight phases including focus booms.

The effects of low noise supersonic overflights on animals will not be tested due to the low likelihood of harmful effects. The extensive literature covering sonic boom impacts on animals tends to show minimal to no reaction except for occasional startle, which is also observed for humans.[10,11] Due to lower noise levels, low noise signatures are expected to elicit even fewer reactions from animals than sonic booms.

While sonic booms are not the only barrier to viable commercial supersonic flight over land, they are the key barrier. Other barriers to supersonic flights to be addressed beyond the Quesst mission include takeoff and landing noise in airport communities, high altitude emissions during supersonic flight, aircraft efficiency in terms of lightweight structures and low drag, and affordability.

KEY POTENTIAL CHALLENGES

One key potential challenge is the possibility of sparse observations of high annoyance in the survey. In recent NASA risk reduction testing across a similar range of noise exposure levels, only about 1% of the observations were highly annoyed.[9] The imbalance between highly and not highly annoyed responses challenges traditional dose-response modeling techniques. One way to mitigate the imbalance is via alternate cut-offs for the annoyance scale resulting in percent at least moderately annoyed, or percent at least slightly annoyed. If this approach is taken, then additional modeling assumptions are required to convert back to the more common cut-off of percent highly annoyed. Exactly where the observations fall along the lower tail of the dose-response relationship will not be known until community test data is collected.

Another key potential challenge is the possibility of high variability between community test sites, which could complicate efforts to establish a single representative dose-response relationship from four to six test sites. The level of variability across airports in the US Federal Aviation Administration Neighborhood Environmental Survey (NES)[12] was acceptable because the sample consisted of 20 airports. While the two studies shown in Figure 3 seem to indicate low variability between test sites, neither study was considered representative. Because low noise supersonic flight is new and very little information is available on community response, the variability in dose-response relationships across community test sites cannot be assessed until the data are collected.

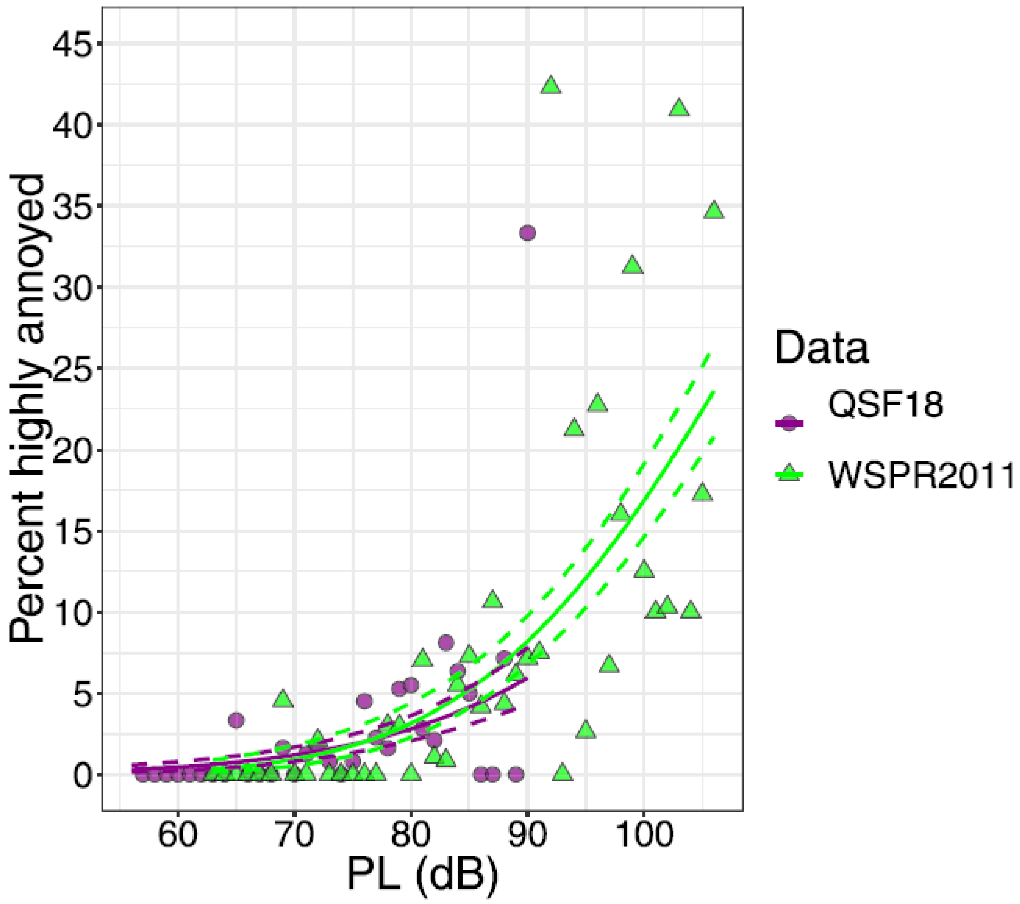

Figure 3: Single event dose-response curves[13] from previous NASA sonic boom community tests.

A third key potential challenge is the possibility of unintentionally influencing survey results via the process of informing the public about the NASA X-59 overflights. The NES, for example, obscured its own intent as a noise survey to avoid inadvertently influencing survey results. NASA's mitigation for this challenge is to keep communications as informative, objective, and unbiased as possible. NASA has assembled a survey-methods expert panel to review both the communications strategy and the communications materials to ensure objectivity.

INTERNATIONAL ENGAGEMENT

Achieving consensus and general concurrence on NASA's overall technical approach is key to ensuring widespread global acceptance of the community test results. To that end, NASA has hosted workshops and briefings with international participation to disseminate Quesst mission plans and solicit feedback on them. The most recent workshop was held in 2021, with presentation materials listed below.[14] Key discussion points from that workshop were also summarized in a recent publication.[15] As a participant in the International Civil Aviation Organization Committee on Aviation Environmental Protection Working Group 1 (Noise), NASA provides regular status updates on the mission progress.

To improve the overall international representativeness of the data, NASA welcomes the opportunity to partner with other organizations to conduct a community test outside the US and is open to discussions on how to coordinate such an effort. NASA estimates that a minimum of two years would be needed to negotiate, plan, and execute a community test internationally. Additionally, NASA welcomes the possibility of collaborating with other research and regulatory organizations during the US community tests to address additional research areas or questions.

CONCLUSION

In its mission to expand knowledge and improve aviation, NASA conducts research to address sonic boom noise, the prime barrier to overland supersonic flight. NASA is planning a campaign of community tests with the X-59 aircraft to collect representative data that describe the community response to low noise supersonic overflights. The data will support efforts to create noise limits for supersonic overflight noise certification standards.

NASA is taking a systematic approach to collecting representative data. The four to six community test locations will represent different geographic regions of the US and will differ in terms of racial/ethnic composition and levels of urbanicity. The number of overflights and month-long test duration have been chosen to give survey participants time to adapt to the new sounds. To enable stable estimates of the dose-response relationship, at least 1000 participants will be recruited for each community test.

The need to focus test objectives means that certain data will not be collected. Nighttime noise exposure cannot be tested in the current timeframe due to operational and safety considerations. Furthermore, community response to focus booms will not be acquired directly because of the difficulty in making accurate noise dose estimates, although the X-59 low noise signature can be made louder by varying the flight conditions. The effect of low noise supersonic overflights on animals will not be tested because adverse effects are not expected.

Achieving consensus and general concurrence on NASA's overall technical approach is key to ensuring widespread global acceptance of the results of the community tests. To improve the overall international representativeness of the data, NASA welcomes the opportunity to partner with other organizations to conduct a community test outside the US and is open to discussions on how to coordinate such an effort. Additionally, NASA welcomes the possibility of collaborating with other research and regulatory organizations during the US community tests to address additional research areas or questions.

In summary, the community test campaign of the NASA Quesst mission is a first major step along the path to a supersonic future. While that path includes other barriers to supersonic flight beyond the scope of the NASA Quesst mission, such as takeoff and landing noise, high altitude emissions, aircraft efficiency, and affordability, the Quesst mission's representative community response data will fill a critical need for international rulemaking. Regardless of what noise limit is ultimately chosen by regulators, the Quesst community test dataset will expand knowledge and set a standard of excellence for community noise studies of the future.

REFERENCES

1. United States Code of Federal Regulations, Title 14 – Aeronautics and Space, Part 91 General Operating and Flight rules, Section 817 Civil aircraft sonic boom.
2. Rathsam J, Klos J, Loubeau A, Carr DJ, Davies P. Effects of chair vibration on indoor annoyance ratings of sonic booms. Journal of the Acoustical Society of America 2018; 143(1): 489-499. https://asa.scitation.org/doi/10.1121/1.5019465
3. Stevens SS. Perceived level of noise by Mark VII and decibels (E). Journal of the Acoustical Society of America 1972; 51(2B): 575-601. https://asa.scitation.org/doi/10.1121/1.1912880
4. ISO/TS 15666:2021 Acoustics — Assessment of noise annoyance by means of social and socio-acoustic surveys.
5. Doebler WJ, Sparrow VW. Stability of sonic boom metrics regarding signature distortions from atmospheric turbulence. Journal of the Acoustical Society of America 2017; 141: EL592. https://asa.scitation.org/doi/pdf/10.1121/1.4986209
6. Nixon, CW, Borsky PN. Effects of Sonic Boom on People: St. Louis, Missouri, 1961-1962. AMRL-TR-65-196.
7. Rathsam J, Loubeau A, Klos J. Effects of indoor rattle sounds on annoyance caused by sonic booms. Journal of the Acoustical Society of America 2015; 138: EL43. https://asa.scitation.org/doi/10.1121/1.4922535
8. Doebler W, Loubeau A. Updated noise dose range of NASA's X-59 aircraft estimated from propagation simulations. Journal of the Acoustical Society of America 2022; 152, A86 https://ntrs.nasa.gov/citations/20220017665
9. Page JA, Hodgdon KK, Hunte RP, et al. Quiet supersonic flights 2018 (QSF18) test: Galveston, Texas risk reduction for future community testing with a low-boom flight demonstration vehicle. 2020. Technical Report No. NASA/CR-2020-220589.
10. Kull RC, Fisher AD. Supersonic and Subsonic Aircraft Noise Effects on Animals: A Literature Survey. 1986. AD-A186-922, AAMRL-TR-87-032 https://apps.dtic.mil/sti/pdfs/ADA186922.pdf
11. Aviation Noise Impacts White Paper State of the Science 2019: Aviation Noise Impacts, References 134-164.
12. Miller N, Czech JJ, Hellauer, KM et al. Analysis of the Neighborhood Environmental Survey. No. DOT/FAA/TC-21/4 2021.
13. Lee J, Rathsam J, Wilson A. Bayesian statistical models for community annoyance survey data. Journal of the Acoustical Society of America 2020; 147(4): 2222-2234. https://asa.scitation.org/doi/10.1121/10.0001021
14. NASA Community Test Workshop 2. https://ntrs.nasa.gov/citations/20210025956
15. Coen P, Loubeau A, Rathsam J, Shah G. Achieving Global Consensus on Acceptable Sound Levels for Overland Supersonic Flight. Proceedings of Internoise 2022; August 21-24, 2022; Glasgow. https://doi.org/10.3397/IN_2022_0993