

NASA's plans to assess annoyance caused by supersonic overflights of the X-59 aircraft

Jonathan Rathsam

NASA Langley Research Center, Flight Vehicle Acoustics Branch, Hampton, Virginia, USA

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 from impacting communities under the flight path. However, reduced sonic boom noise levels may be achieved via new aircraft shaping techniques that limit the merging of shockwaves generated during supersonic flight. NASA's piloted research aircraft, the X-59, was built to demonstrate reduced sonic boom noise during supersonic flight and took its first flight in October 2025. After the completion of 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 noise from this new design. The data will support the efforts of national and international noise regulators to develop new standards that would allow supersonic flight over land at reduced noise levels. This paper summarizes key research results on which the X-59 community surveys are based, as well as current plans for NASA's X-59 community survey campaign.

Keywords (3-6): 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, meaning less time en route and more time at destinations. Current regulations that prohibit civil supersonic flight over land¹ are the prime barrier to this vision. When this speed restriction was first introduced a half century ago, it was intended to prevent sonic boom noise from disturbing communities.

In recent decades, the research community has developed new designs for supersonic aircraft that produce what is called a shaped boom, with reduced noise relative to a typical sonic boom (traditional N-wave), as shown in Figure 1. Simulated shaped booms are rarely perceived as annoying, whether in laboratory tests or field tests. However, shaped booms from a purpose-built supersonic aircraft have never been tested over a representative population to gather community response. The community survey 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.

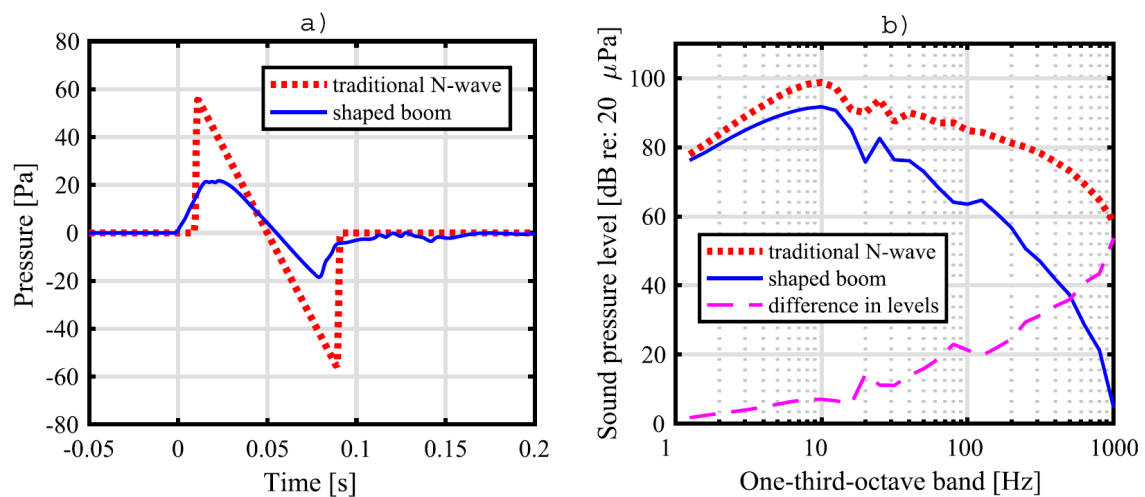


Figure 1: Simulated (a) time histories and (b) one-third-octave band sound pressure levels for a traditional N-wave sonic boom and a reduced noise signature (i.e., a shaped boom).²

To put shaped booms in context with other impulsive sounds, the graphic in Figure 2 shows a range of impulsive environmental sounds arranged by loudness. The NASA X-59 was designed to achieve a shaped boom, which is comparable to distant thunder or a car door shutting from across the street. This sound is much lower in level than the sonic boom from the Concorde, which is comparable to nearby thunder or a car door slam from inside the car.

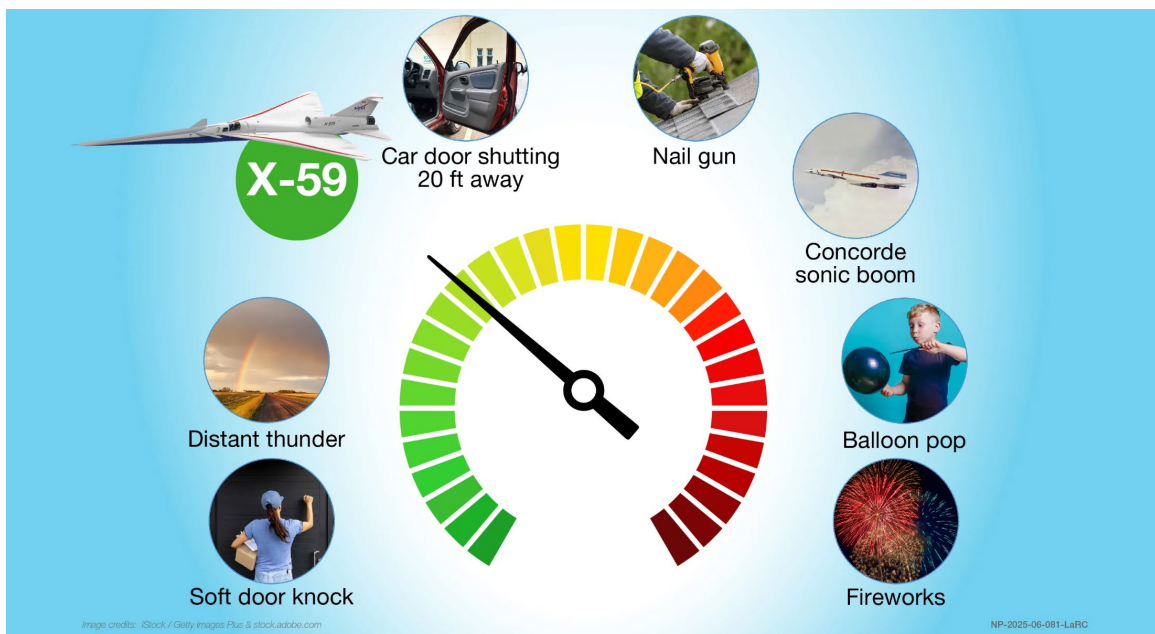


Figure 2: Comparison of sound levels among X-59, Concorde sonic boom, and other impulsive environmental sounds.³

PAST RESEARCH

Historic Studies

In the early decades of supersonic flight, many studies were conducted both in the laboratory and in the field to learn more about human response to sonic boom noise.⁴ Two influential studies were community surveys in St. Louis and Oklahoma City, which lasted a half year each. In St. Louis there were 76 sonic booms, and in Oklahoma City there were more than 1200 booms. From these surveys, two key results were identified: 1) conventional sonic booms are not publicly acceptable, and 2) of the factors shaping human response, indoor annoyance was the most important. Many decades of research and careful study have led researchers to the conclusion that the loudness and annoyance of supersonic flight can be reduced through careful design of the aircraft shape. Beginning in the early 2010s, a new generation of research has been undertaken to better understand community response to reduced sonic boom noise. The initial community surveys of this era used an F-18 performing a low-boom dive maneuver to simulate a shaped boom, but X-59 will fly steady and level in its survey campaign because it is a low-boom airplane. A summary of NASA community surveys in this timeframe is shown in Table 1.

Table 1: Summary of NASA community surveys.

Title	Aircraft / Flight maneuver	Location	Year	Number of Survey Participants	Number of noise events	Research Goal
Small Community Survey	F-18 / low-boom dive	Edwards, CA	2011	100	110	Pilot Study
Large Community Survey	F-18 / low-boom dive	Galveston, TX	2018	500	52	Risk Reduction
Survey Methods Test	n/a	Nashville, TN	2023	500	n/a	Risk Reduction
X-59 Community Survey Campaign	X-59 / steady level flight	Multiple, TBD	Planned for late 2020s	1000 per site	~80	Data for Regulators

Small Community Survey

In 2011, a small community survey was conducted over ten days at Edwards Air Force Base in California on approximately 100 participants split into two panels.^{5,6} The survey was a pilot study to demonstrate research methods and compare survey modes to investigate prompt responses to shaped sonic boom events. Each day, there were between 4 and 13 sonic booms at various amplitudes during daytime hours. A NASA research aircraft flew a supersonic dive maneuver to simulate a shaped boom. Three survey modes were employed: paper, web, and smartphone. All survey data modes were approximately equally successful, with no single mode clearly superior in terms of completion rate or participant experience. One lesson learned was to separate noise exposures by at least 20 to 30 minutes to ensure that responses could be reliably associated with specific noise events. Manual triggering of recording on the noise measurement kits was used for data collection, but an automated recording and boom-finding algorithm was developed and recommended for the future so kits could be operated in auto-mode without dedicated triggering.

Large Community Survey

In 2018, a large community noise survey was conducted over a two-week period in Galveston, Texas⁷ using a NASA research aircraft flying a supersonic dive maneuver to simulate a shaped boom. The research goal was risk reduction by demonstrating that NASA could successfully engage with a community to execute a community noise survey using a NASA research aircraft. The lessons learned included conducting early community engagement, with separate tailored engagements for local air traffic control, elected officials, the public, and survey participants. In terms of the survey, reminder messages sent to survey participants helped improve survey completion rates. For all data collected, the need for automation in data reduction and analysis was identified, especially if in the future multiple community tests would be planned within a single calendar year.

Survey Methods Test

In 2023 a multi-week survey methods test was completed with members of the public in Nashville, Tennessee.⁸ The goal of this test was risk reduction by verifying that the survey methods developed for X-59 tests would function as desired. Because there were no flyovers by X-59 or other supersonic aircraft, respondents were asked about their reactions to noise from ongoing subsonic aircraft operations. The address-based sampling method enabled a representative sample of 800 residents to be recruited from an area equivalent in size to an X-59 survey site. A graduated incentive structure kept respondents engaged, with higher incentives for higher survey completion levels and for each subsequent week of the test. Location data were also collected from respondents since they will be needed to estimate individual noise exposure for each noise event from X-59. The survey methods test enabled successful execution of the full survey process, with response rates consistently between 40% and 60%, which exceeded expectations. Some additional lessons learned included the importance of automation in critical processes and the vulnerability of systems to network and server problems.

PLANNED RESEARCH

Scope of X-59 Community Survey Campaign

The primary research goal of the X-59 community survey 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. Additional survey questions will assess the following secondary research goals: 1) Assess the effects of indoor noise-induced rattle sounds and vibration on dose-response relationships, 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), and 4) Assess the prevalence of “startle” (i.e. the feeling of sudden shock or alarm), which was a major component of annoyance in historic sonic boom community surveys.

To collect nationally representative dose-response data, NASA will conduct community surveys at up to five sites representing different geographic regions of the US. The sites will also differ in terms of racial/ethnic composition and levels of urbanicity. For each community survey, NASA anticipates conducting up to 6 supersonic overflights (single events) per day, totaling an estimated 100 such events per survey over a month. This number of overflights and month-long survey duration have been chosen to give survey participants time to adapt to the new sounds. For each community survey, NASA intends to acquire survey responses from a probability-based sample of at least 1000 participants.

As described in Rathsam et al.,⁹ the need to focus survey objectives means that certain data will not be collected. For example, the effects of nighttime supersonic overflight noise exposure, including possible sleep disturbance, will not be studied in the current timeframe due to a combination of operational and safety considerations. Community response to focus booms created when the X-59 accelerates into supersonic flight will not be acquired. The effects of reduced noise supersonic overflights on animals will not be tested due to the low likelihood of harmful effects. While sonic booms are the key barrier, they are not the only barrier to viable commercial supersonic flight over land. 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.

The following sections illustrate the high degree of technical consideration across a range of methodological topics to maximize the robustness and validity of the X-59 community survey data.

Dose-Response Modeling

The dose-response model will be summarized via a quantitative relationship, or a summary curve, that describes the fraction of people highly annoyed as a function of noise exposure. Annoyance is assessed in the survey as an ordinal variable on a 5-point verbal scale. By convention, the 5-point scale is converted into a binary outcome of highly annoyed vs not highly annoyed.¹⁰ Noise exposure is a continuous variable, estimated based on the participant's reported location during each flyover. Separate dose-response models are planned for single-event exposure, or single overflights, and for cumulative exposure from multiple flyovers throughout the day.

A common modeling approach is the simple logistic regression model, in which the probability of being highly annoyed depends only on the noise exposure level. The simple logistic regression model can be made more sophisticated by including other covariates, such as demographic variables like age, race, and ethnicity; housing variables like type of dwelling (single-family home, apartment, etc.); or location variables like urbanicity and population density, as well as interaction effects.

Some individuals may have a higher or lower threshold for annoyance compared to other individuals despite having the same demographic, housing, and/or location characteristics. While the simple logistic regression model described above includes the effect of these characteristics, it does not account for additional individual-level variation not captured by other covariates. For this reason, a multilevel logistic regression may be introduced to account for this effect.

Other possible modeling approaches include ordinal regression and multilevel ordinal regression,¹¹ which model the cumulative probability of responding at each annoyance level. Another model under consideration is a two-stage model. The first stage models the probability that a participant ever responds as highly annoyed given demographics, and the second stage models the probability of high annoyance, but is fit only on the participants who responded at least once as highly annoyed.¹² This collection of potential analysis techniques serves as a toolchest to be drawn from once the data are collected. Multiple modeling methods will be evaluated on the dataset for the sake of comparison.

Measurement Error Corrections

One factor that can distort a dose-response curve is measurement error.¹³ Measurement error is the difference between the observed, or measured, noise dose and its true, unknowable value. When measurement error is not properly accounted for, it can artificially flatten a dose-response curve, causing overestimated annoyance at low noise doses and underestimated annoyance at high noise doses.

Several techniques exist to correct for measurement error, including regression calibration, simulation extrapolation (SIMEX), structural Bayesian hierarchical models, and data cloning. A NASA review found that structural Bayesian hierarchical models may be most readily applicable to X-59 community surveys because of their flexibility and ability to propagate uncertainty from the individual level to the population level.¹⁴ The Bayesian techniques were also demonstrated by Erciulescu and Opsomer.¹⁵ Measurement error will be estimated for X-59 shaped sonic boom measurements starting in the acoustic validation phase, prior to community testing, and the techniques described above will be exercised on the X-59 community survey data to identify whether measurement error is present and, if so, to correct for it.

Control Condition

A control condition is defined as a condition in an experimental design that does not involve exposure to the treatment or intervention under study.¹⁶ For the X-59 community survey, a control condition is planned to assess annoyance in the absence of X-59 flights, as well as during X-59 flights. Including a control condition is foundational in research experiments with human subjects and necessary for valid inferences.

While specific analysis techniques for the control condition data are under development, in general the data will help guide the interpretation of dose-response curves. For example, a control condition was included in the large community study described in the previous section, and the result was that some participants were highly annoyed even when no flight occurred. The proportion highly annoyed under the control condition presents a plausible lower limit on annoyance that can be reliably assessed and attributed to noise from the supersonic flight. A similar analysis is planned for the control condition data during the X-59 community survey.

Carryover Effects

Carryover effects occur when a person's exposure to a previous experimental condition influences their response to the current experimental condition. Carryover effects can be a source of response bias, causing the reported response to differ from the actual response. While it is rarely possible to fully avoid carryover effects, their presence or absence can sometimes be confirmed via analysis, and some methodological steps can be taken to reduce their severity. For example, randomizing the presentation order of noise dose levels can help minimize potential effects of presentation order.

Other potential carryover effects include decisional carryover, habituation, and contrast effects. Decisional carryover is the effect of previous annoyance responses on the annoyance rating of the subsequent booms. Habituation is when a participant becomes acclimated over time and becomes less annoyed, and a contrast effect is the opposite, when a participant becomes more annoyed as time progresses. NASA's choice of a monthlong duration for each X-59 community survey was based on judgment rather than data and intended to give participants time to adapt to the new noise.

In the X-59 community surveys, where aircraft operational considerations and safety are the top priority, and factors such as weather cannot be controlled, the methodological steps that

can be taken to reduce carryover effects are limited. However, analyses will be undertaken to identify potential carryover effects in the data, some of which were demonstrated notionally by NASA authors on laboratory data.¹⁷

Combining Multiple Survey Sites and Generalizing to the Population

To support the development of noise limits, a single representative dose-response curve is desired rather than multiple curves. However, to be representative, the curve must stem from surveys conducted at multiple geographically diverse locations. Therefore, two methodological processes are needed: first, a process to determine whether combination of multiple community surveys is warranted by the data (i.e., whether the data are consistent enough to justify merging data); and second, a process to combine the survey results into a single dose-response curve.

A NASA report reviewed relevant literature and provided several tools to assess the data similarity among two or more survey sites.¹⁸ The first tool is the confidence band overlap, which divides the range of noise exposure levels over which the confidence intervals intersect for percent highly annoyed by the total range of noise exposure levels common to two survey sites. A simulation study found that at least 11% of the noise exposure level range should overlap for the data between two sites to be considered similar. The second tool is the intraclass correlation coefficient, or variance partition coefficient, which measures the proportion of variance attributable to difference between groups in hierarchical data. A value closer to 1 implies significant clustering, while a value closer to 0 implies that the data are more similar across survey sites. Finally, the third tool is a comparison of the proportion of highly annoyed responses at the highest noise exposure level bin across two or more survey sites using the Marascuillo procedure to compare all possible pairs of proportions.

The ultimate techniques for merging the data will depend on characteristics of the actual data collected, especially whether all, just a subset, or none of the data across sites are considered consistent enough to merge.

CONCLUSIONS

To collect nationally representative data on the human response to reduced sonic booms, NASA will conduct a campaign of X-59 community surveys at up to five sites in different geographic regions of the US. This paper summarizes some of the key methodological and experimental design decisions made to maximize the validity of the results. For the dose-response statistical model, several promising techniques have been identified, including multilevel logistic regression and a two-stage model. To minimize the potential for distortion in the dose-response curves, techniques such as structural Bayesian hierarchical models will be used to attempt to account for measurement error. A control condition is planned to assess baseline annoyance without any X-59 flights and help ensure valid inferences from the survey data. The survey data will be analyzed for evidence of carryover effects, even though it may not be possible to fully avoid these effects via experimental design. Finally, careful consideration will be given to the question of if and how data from multiple survey sites are combined into a single, representative dose-response relationship.

Acknowledgements

The HMMH Team, especially Westat, is acknowledged for work supported by NASA under Contract 80LARC21DA001.

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, and Davies P. Effects of chair vibration on indoor annoyance ratings of sonic booms. *J Acoust Soc Am* 2018; 143(1): 489-499. <https://doi.org/10.1121/1.5019465>
- [3] <https://www.nasa.gov/wp-content/uploads/2023/07/sound-gauge-150rgb-pub.jpg>
- [4] von Gierke HE and Nixon CW. Human response to sonic boom in the laboratory and the community. *J Acoust Soc Am* 1972; 51(2C): 766-782. <https://doi.org/10.1121/1.1912909>
- [5] Page JA, Hodgdon KK, Kreckler P, et al. “Waveforms and Sonic Boom Perception and Response (WSPR): Low-Boom Community Response Program Pilot Test Design, Execution, and Analysis” NASA/CR–2014-218180. <https://ntrs.nasa.gov/citations/20140002785>
- [6] Fidell S, Horonjeff RD, and Harris M. Pilot Test of a Novel Method for Assessing Community Response to Low-Amplitude Sonic Booms. NASA/CR–2012-217767. <https://ntrs.nasa.gov/citations/20120014937>
- [7] 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. <https://ntrs.nasa.gov/citations/20200003223>
- [8] Rathsam J. Overview of A Survey Methods Test for the NASA Quesst Community Survey Campaign. DATAWorks 2024, April 16-18, 2024; Alexandria, VA. <https://ntrs.nasa.gov/citations/20240003803>
- [9] Rathsam J, Coen P, Loubeau A, Ozoroski L, and Shah G. Scope and goals of NASA’s Quesst Community Test Campaign with the X-59 aircraft. ICBEN 2023, June 18-22, 2023, Belgrade, Serbia. <https://ntrs.nasa.gov/citations/20230004142>
- [10] [ISO/TS 15666:2021](#) Acoustics — Assessment of noise annoyance by means of social and socio-acoustic surveys.
- [11] Lee J, Rathsam J, and Wilson A. Bayesian statistical models for community annoyance survey data. *J Acoust Soc Am* 2020; 147(4): 2222-2234. <https://doi.org/10.1121/10.0001021>
- [12] Ferg R and Opsomer J. Modeling approaches to estimate community annoyance due to sonic booms using data from repeated surveys. 7th Italian Conference on Survey Methodology (ITACOSM 2022). June 8-10, 2022. <https://ntrs.nasa.gov/citations/20220008195>
- [13] Horonjeff R. An examination of dose uncertainty and dose distribution effects on community noise attitudinal survey outcomes. *J Acoust Soc Am* 2021; 150(3): 1691-1701. <https://doi.org/10.1121/10.0005949>
- [14] Cruze N. Summary and Annotated Bibliography of Measurement Error Corrections with Potential Application in Future Quesst Mission Community Noise Studies. NASA/TM–20240015301. <https://ntrs.nasa.gov/citations/20240015301>
- [15] Erciulescu A and Opsomer J. Accounting for Dose Uncertainty in Dose-Response Curve Estimation Using Hierarchical Bayes Models. Joint Statistical Meeting, August 5 – 10, 2023. Toronto, Canada. <https://ntrs.nasa.gov/citations/20230007198>
- [16] American Psychological Association. (n.d.). Control condition. In *APA dictionary of psychology*. Retrieved March 13, 2026, from <https://dictionary.apa.org/control-condition>.
- [17] Ballard K, Vaughn A, Doeblner W, and Rathsam J. Analysis of carryover effects in a low boom laboratory listener study. *Proceedings of Meetings on Acoustics* 45(1), 040002 2021. <https://doi.org/10.1121/2.0001566>
- [18] Ballard K, Boucher M, Cruze N, and Doeblner W. Methods for Combining Results from Multiple Community Tests. 2025. <https://ntrs.nasa.gov/citations/20240015326>