

Achieving Global Consensus on Acceptable Sound Levels for Overland Supersonic Flight

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Abstract

The National Aeronautics and Space Administration has made a commitment to deliver to the International Civil Aviation Organization’s Committee on Aviation Environmental Protection (ICAO CAEP) data defining community response to sounds from supersonic aircraft designed such that their sonic boom is replaced with a soft “thump” sound. The dataset will be a correlation of public perceptions of these sounds to the corresponding acoustic levels. The data will support efforts to develop international standards for permissible noise from supersonic overflight. NASA is planning and preparing for a series of community overflight tests with the X-59, a unique research aircraft capable of generating the “sonic thump”. NASA will begin these tests in 2024.

With an eye toward achieving global consensus for noise standards, NASA’s goal is that the community response data be as broadly representative of the response of the international population as possible. As such, NASA is engaging the international regulatory and research communities in both the planning and execution of these tests, through status briefings at ICAO CAEP-sponsored meetings and through workshops with international participation. As part of this outreach NASA held a virtual workshop in December 2021 focused on strategies and considerations for estimating noise exposure levels and conducting surveys to characterize community annoyance levels relative to the “thump” sounds.

This paper will present an overview of NASA’s effort, with a focus on the plans and technical goals for the community response tests. In addition, results of the recent workshop will be briefed, including considerations and approaches for ensuring broad representativeness of results and approaches for estimation of the sound levels across the test community. Participant feedback from both the workshop and previous engagements will be discussed, along with how it is being addressed in NASA’s ongoing planning efforts.

Introduction

With renewed global interest in commercial supersonic flight by manufacturers, air carriers, and the flying public, attention has focused on overcoming the technical barriers to make such travel economically and environmentally viable. One significant barrier from a regulatory standpoint is that commercial overland supersonic flight is prohibited by most nations because of the unacceptably loud sonic booms generated by such aircraft.

Technological advances, however, have made possible the development of aircraft that will fly at supersonic speeds without creating a sonic boom like that of the Concorde or current military aircraft. The sound of these aircraft will be a soft “sonic thump” that is expected to be acceptable to people on the ground. This new technology makes it possible to pursue the development of an internationally-accepted standard for acceptable noise levels for supersonic overland flight to replace the current prohibitions. In keeping with its strategic vision to create aviation systems that are global, transformative and sustainable, NASA is supporting the global supersonics community’s efforts to open new markets by investing in both technology development and creation of scientifically rigorous data needed to overcome the barriers to supersonic flight over land.

The development and adoption of a noise standard of acceptable sound level requires, as its basis, a set of data relating the public’s annoyance level to the sound level of the sonic boom. The NASA Quesst mission and X-59 aircraft are specifically intended to generate that key dataset.

As part of its strategic plan for supersonic flight, NASA has committed to delivering a dataset of nationally representative community response to sonic thump sounds to the International Civil Aviation Organization’s (ICAO) Committee on Aviation Environmental Protection (CAEP). The dataset will be a correlation of public perceptions of sonic thumps to their acoustic levels, and will be used to support efforts to develop international standards for permissible noise from supersonic overflight.

To collect the data, NASA’s Quesst mission is planning a national campaign of four to six community overflight tests using the X-59 aircraft. Each community test entails a series of supersonic overflights occurring over a period of approximately one month, preceded and followed by preparation/setup and closedown activities. The current plan is for the test campaign to occur in the 2024 through 2026 timeframe, with approximately two tests in different locations per year (thus roughly one test every six months). This overall timeframe and test cadence is intended to correspond with ICAO’s plans to propose a supersonic en route noise standard to the CAEP/14 meeting in 2028.

The overflight test campaign is one of three phases of the overall Quesst mission:

Phase 1 involves X-59 aircraft development activities from detailed design through fabrication and flight test, concluding with functional checkouts and supersonic envelope expansion, resulting in operational readiness for research activities. Phase 1 is currently underway, with anticipated completion in 2023.

Phase 2 entails conducting low-boom acoustic validation flights of the X-59 aircraft. These flights will be conducted in the supersonic test ranges near NASA’s Armstrong Flight Research Center (AFRC) to characterize and evaluate the near-field, mid-field, far-field, and ground acoustic signatures from the X-59 aircraft. This characterization will include the effects of changing atmospheric and aircraft flight conditions. The goal of Phase 2 is to validate computational tools for the propagation and prediction of the X-59 acoustic signature, and

confirm the aircraft's ability to generate the designed sound levels from the sonic thump. Phase 2 is scheduled to be conducted in the 2023-2024 timeframe.

Phase 3 is the community test campaign. The first of these tests will be conducted via X-59 flights operating out of NASA AFRC in Southern California. Surveyed communities for this test will be selected from locales within the X-59 operational range from AFRC that are not acclimated to hearing sonic booms. The purposes of this first community test are to validate all the elements of the test process and conduct an initial exploration of community response to sonic thump sounds through a full data collection/analysis effort, without the complication of conducting experimental flight operations at a location away from the full ground support available at NASA AFRC. The remaining community overflight tests will be conducted over various locations across the United States to capture survey responses from a representative spectrum of communities under different geographic and meteorological conditions.

Planning and preparation for Phase 3 is comprised of efforts across three main areas: airfield and community test site selection; survey design and analysis; and exposure design and estimation. Results from surveys and exposure estimations conducted during the overflight tests will be used to develop nationally-representative dose-response relationships between the sonic thump acoustic levels and public annoyance levels. This overall effort is being conducted by a large NASA and contractor team composed of specialists with expertise across all related technical areas.

Airfield and Community Test Site Selection

Determining the locations for the community tests involves numerous considerations, including operational and safety constraints related to the X-59 aircraft, and technical requirements for both sufficiency and diversity in survey community population demographics, geography, and urbanization levels.

Airfield selection must consider X-59 operational requirements such as runway dimensions and surface condition, adequate available infrastructure such as hangar space, ground support equipment, security, as well as local airfield and airspace operations and air traffic density. In addition, availability of an adequate population center within the aircraft's operational range must be considered, along with the ability to place a focus boom (a sound typical of supersonic flight that occurs when an aircraft first accelerates to supersonic speed) over an unpopulated region (such as overwater) outside of the community test area.

From the community test standpoint, a number of other considerations come into play, including ensuring geographic and climate zone variation of the test locations across different areas of the US. In particular, climate differences (such as hot/humid versus cold/dry) can influence the propagation of the X-59 acoustic signature to the ground, requiring testing in different regions of the country. Urbanization levels, ranging from rural to suburban to urban, may influence survey responses via differences, for example, in ambient noise level at the participant location.

In terms of the survey participants themselves, diversity of key population demographics, such as gender, age, and race/ethnicity must be considered, along with the participant's environment at the time of the supersonic overflight (e.g., home/work location, current activity, time of day, etc.).

With only a limited number of tests possible given the logistical, technical, and time constraints of the overall Quesst mission, it may not be practical or possible to conduct an overall test campaign that would be considered fully statistically significant with respect to all of the above considerations. Therefore, a purposive sampling approach is being used to determine airfield and community test locations, focusing on what are expected to be some of the major influences on overall community response, including climate zones and population density (urbanization level). Although it is not known to what degree the key population demographics (as stated above) influence community response, they will also be considered in this approach, to ensure that representativeness of the national population is reflected in the participant pool.

As described earlier, the first community test will be conducted by operating the X-59 out of NASA AFRC, with the community test area still to be determined. For the remaining tests, because of the long lead time until actual community tests and the potential for significant changes at a given airfield or test site over the next 2-4 years, multiple candidate sites will be identified through the selection process and continuously evaluated for acceptability. The final intended test location will be determined/announced roughly 1-2 years prior to each specific test.

Survey Design and Analysis

The primary goal of conducting surveys during the community tests is the development of an accurate nationwide estimate of the single-event and cumulative dose-response relationship between the proportion of the population annoyed (to varying degrees) by supersonic overflights and acoustical data (measured and modeled) that characterize noise exposure. Secondary goals include assessing the effects of other aspects on sonic thump perceptions and annoyance levels, including indoor noise-induced rattle sounds and vibration, participant location (e.g., home or work location, indoor or outdoor, or indoor with windows open/closed), and time-of-day (daytime or evening). Assessing the prevalence of "startle" in perceptions/annoyance of sonic thumps is also a secondary goal.

Key efforts related to the development of survey methods include determinations of appropriate sample sizes of participants and the related recruitment plan, creation of recruitment materials and information dissemination strategies, and creation of relevant questionnaires to characterize annoyance levels. Development of techniques for analyses of the survey data include evaluating statistical models for fitting of the data (including processing time), methods for fitting statistical models (Reference 1), and methods for matching survey responses with participant location (to correlate response with the appropriate sound level).

To address and support these efforts, researchers are developing simulated dose-response datasets to study the influences of various aspects, including number of participants, test points, and dose uncertainty. The studies will support the development of appropriate data sufficiency

and success criteria for the ultimate community test results. Studies into potential carryover effects (influence of past dose levels on current response) from earlier research are also being conducted, in order to assist in the design and scheduling of noise exposure levels from the X-59 during the community tests.

In preparation for the community overflight tests, NASA and its contract partners will be conducting a test of the survey methods with members of the public. The test, which will not involve any actual flights, will involve the entire survey process, including recruitment, survey data acquisition, and data analysis, over a period of roughly 30 days, a duration similar to an actual community test. This survey test will be used to assess recruitment response rates and participant attrition; evaluate survey instruments (mobile app and web interfaces) and questions, and verify methods for identifying participants' locations. This survey test is anticipated to be conducted in 2022 at a still-to-be-determined location in the US.

To facilitate and ensure global acceptance of the NASA technical approach, and because the development, application, and analysis of public surveys is not a traditional area of expertise for the agency, NASA is engaging a panel of several experts to provide a third-party review of its survey-related activities. This team of reviewers from organizations outside of NASA all have expertise in survey methods, survey analyses, and/or noise annoyance. During the community test planning stage, this panel will review and provide feedback of the overall survey methods and analysis plans to NASA to ensure technical quality and relevance.

Exposure Design and Estimation

While the X-59 is being designed to create a sonic thump with a sound level of 75 dB in PL (Perceived Level in decibels) during cruise flight, the levels the survey participants will experience are intended to encompass the range of sound levels that will be produced by future supersonic passenger aircraft. Different levels will be achieved by varying the aircraft speed, altitude, and trimmed control surface positions. By creating between 1 and 6 sonic thumps per day over a roughly 30-day period, approximately 80 to 90 total unique exposure events will be experienced by the participants (flights will not occur every day). The exposure design approach will allow for varying the levels and number of events to achieve the overall desired range and distribution. Randomization of time of day and weekday/weekend flights will also occur. The current exposure design calls for PL values to range between approximately 70 dB and 87 dB for single events, with a cumulative Perceived Level Day Night Level (PLDNL) dose range of approximately 20 dB to 45 dB. The single-event PL range of 70-87 dB was determined from studying the potential sound levels that could be achieved from aircraft operating conditions as well as the effect of geographic, meteorological, and seasonal variations at potential test locations across the US.

Sound exposure across the test community will be determined by combining measured levels with calculated levels. The resulting "carpet" will be used to determine the exposure level at each survey participant's location at the time they experience the thump.

Ground measurements of the X-59 acoustic signature will be acquired using a state-of-the-art sonic boom measurement system (Ground Recording System, or GRS) being designed and developed by NASA and a contractor (Reference 2). This system, comprised of up to 150 individual portable units, will be used for measurements during X-59 acoustic validation (Phase 2), as well as for the community tests. During the community tests, the GRS will record acoustic signatures during X-59 overflight, compute the necessary sound metrics, and transmit information from each unit to a central operations facility in the test area.

The acoustic signature and sound metrics will also be calculated using the actual X-59 flight trajectory and configuration (speed, altitude, control surface positions, etc.). The calculation will include meteorological data from measurements made before and during flight within the test area.

Measured and calculated levels will be combined through data fusion techniques that will take into account uncertainties in acoustic, meteorological, and flight data measurements.

Some of the challenges in exposure estimation involve determining the scope of required meteorological measurements, automation and processing of measured and calculated sound levels in a timely fashion to support the planned flight rates, and developing appropriate strategies for GRS unit placement to minimize uncertainty in overall carpet estimation. To address the processing challenges, research is being conducted toward the development of algorithms to find and extract low-boom signatures in the presence of ambient noise from the GRS recordings, including the creation of mock X-59 recordings to evaluate those methods. With regard to GRS locations, research is being conducted to study the effects of various GRS placement strategies (Reference 3), incorporating variations from sound and meteorological measurements, on overall uncertainty levels.

Achieving Consensus on Community Test Plans and Strategies

Achieving consensus and general concurrence on NASA's overall technical approach is key to ensuring widespread global acceptance of the results of the community response tests. To that end, NASA has hosted workshops and briefings with international participation to disseminate Quesst mission plans and solicit feedback on them. As a participant in ICAO CAEP Working Group 1 (Noise), NASA has regularly provided status updates on the mission progress during the CAEP/11 and CAEP/12 cycles, and will continue to do so during the current CAEP/13 cycle.

In 2019 NASA hosted an international virtual workshop to disseminate findings from a community test risk reduction study conducted in 2018 in Galveston, Texas, USA. The primary objective of this study, named Quiet Supersonic Flights 2018 (QSF18) (Reference 4), was to evaluate some of the methods and processes that are intended for use in the Quesst community tests. In addition to providing a summary of the QSF18 test and its results, NASA solicited input from the international community at large on considerations for community testing, and received feedback that is being incorporated into its current plans. An important feature of QSF18 is that it used simulations of sonic thump sounds in a real (but small by design) community. The sounds

were created using a special maneuver flown by a NASA F-18 aircraft. The maneuver is designated the "low boom dive".

More recently, in December 2021, NASA hosted a second international virtual workshop to present the current status and timeline for the Quesst community tests, as well as provide some detail on the technical approaches for site selection, survey design, and exposure estimation as described previously. The key goal of the workshop was to obtain general feedback from the international community on those technical approaches, including identification of any significant concerns on the suitability of those approaches and resulting dataset as the basis for development of an international en route supersonic noise standard. The workshop presentation materials and recordings can be found at the weblink in Reference 5.

This 2021 workshop enjoyed broad international participation, with over 120 attendees from 18 countries, spanning over 50 organizations representing research, regulatory, government, academia, and industry interests. Active and robust technical interchanges and discussions were held over the 2-day workshop, resulting in valuable feedback for NASA's consideration. Some of the key discussion points, inquiries, and takeaways from the workshop are summarized below:

- Inquiries were made on how NASA would address building effects, including the effects of differences in construction type on the indoor noise exposure, as well as the influence of rattle and vibration and open windows on indoor annoyance. NASA will be addressing building effects via survey questions on vibration and rattle, building type, and whether windows are open or closed. Building effects are also being addressed through the community test site selection process, as construction types may differ between geographic regions and/or climate zones. The question of just how significant the differences in construction types actually are across regions or climate zones (and their effect on annoyance) is still under consideration; however, it is at least anecdotally assumed there is an influence.
- Questions on addressing the effect of nighttime flights on communities were discussed. In consideration of the increased risk of night test operations, the current scope of the Quesst community tests is limited to flights during waking hours, either daytime or early evening, and is not expected to provide data that would be applicable to assessing effects of nighttime flights, sleep disturbance, etc. This raised the question of whether a standard can be established without such data. More attention should be given to this subject and NASA encourages the international community to consider research opportunities that could be undertaken. It is noted that nighttime exposure to sonic thump sounds would be minimal for the first decades of supersonic commercial operations, offering an opportunity to build a database of the effects of such operations.
- Discussion was held on the influence of ambient noise on community response. NASA is addressing this potential effect by using the surrogate measure of population density, which correlates with ambient noise. As described earlier, the community test site selection process will include ensuring diversity in population density. Post-hoc statistical analyses will address the degree of association between population density and community response.

- The relevance of single-event versus cumulative dose-response curves was discussed. There are perspectives that both should be considered important, though for different aspects regarding the development of a noise standard. From a certification standpoint, single-event levels may be considered the priority in developing a standard and defining procedures, while both single-event and cumulative levels may be relevant for assessing overall community response and impact. NASA will be providing both as part of its deliverable to ICAO-CAEP. Methods and significance of being able to relate one to the other continues to be an open research question.
- Questions were raised about how to account for atmospheric turbulence effects in estimating the noise dose, as well as how to measure turbulence. NASA will address turbulence through measurements and by modeling its effects on boom propagation. Determining the spatial and temporal resolution for adequate precision in estimates is still under consideration. Plans are underway to develop flight planning and noise exposure estimation processes to incorporate the turbulence effect on mean levels and variability.
- The level of uncertainty expected for noise dose estimates is unknown, but NASA expects a lower dose uncertainty than in previous tests that used the F-18 low-boom dive maneuver, since the X-59 sound exposure is predicted to be more uniform. NASA is developing processes to calculate uncertainty in measurements and modeling due to a variety of factors, and experience during the Quesst Phase 2 flights is expected inform the finalization of these processes.
- A question on post-boom noise led to some discussion on this phenomenon of noise that follows the boom, the origin of which is still not fully understood, particularly the extent of such noise following a sonic thump. However, past research has shown that post-boom noise is not considered a significant factor for annoyance ratings. How to handle this factor in data processing is still being determined, but it is probable that the effect on noise metrics will be very small.
- Additional aspects which entailed inquiries and discussions:
 - The impact of testing during rest periods (e.g., weekends/holidays) is incorporated into the NASA exposure design plan, which will randomize conducting flights on weekdays and weekends.
 - Past experience with and attitudes towards sonic booms among survey participants will not be addressed by NASA in order to avoid comparisons and influences on the survey results.
 - NASA does not plan to make indoor measurements at respondent households, due to the complexity and resources required. However, modeling of indoor thump levels for a variety of household constructions may be possible, in order to better understand the respondents' experience in an indoor environment.

- Secondary sonic boom measurements during community testing are not a part of the Phase 3 plan.
- NASA plans do not address the risk of a significant environmental consequence like snow avalanches, as those risks are considered very low.
- Recommendations were also made regarding examining the impact on children's performance in schools, and the impact of the scope of media and NASA information dissemination on annoyance levels. While such recommendations are being considered, it is unknown yet if or how they will be factored into the NASA plans.
- General discussion and interest also focused on the overall representativeness of the US-based dataset to the global community. Some recommendations to expand the survey questions to address broader relevance were made, and are being considered and/or incorporated into the planning.
- To improve the overall international representativeness of the data, NASA welcomes the opportunity to partner with other organizations to conduct an international community test 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.

NASA intends to conduct additional forums for dissemination of the technical plans as they mature during the planning stage in preparation for the community tests.

Summary

Progress and preparations towards the NASA Quesst mission's community response testing for quiet supersonic overflights is continuing. Technical and logistical challenges are being addressed by a broad NASA and contractor team with expertise in all areas needed to support activities on test site selection, survey design and analysis, and exposure design and estimation. The planning stage for community testing will continue through 2023, with supersonic overflight tests scheduled for 2024 through 2026, and results to be delivered to ICAO in 2027 during the CAEP/14 cycle. NASA will continue to engage with the broad international community to disseminate technical plans and solicit feedback on the overall approach in an effort to ensure global consensus on the acceptability of the community response dataset towards the development of an international en route supersonic noise standard.

References

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