NASA's Quesst Community Survey Campaign with the X-59 Aircraft

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October 30, 2023

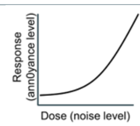
In a few years, NASA is slated to begin a nationwide community survey to understand how people respond to low noise supersonic overflights.

NASA will use this one-of-a-kind X-59 experimental aircraft, but the results will generalize to any future supersonic aircraft.

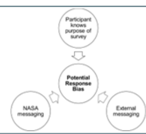
On behalf of my coauthors, I am pleased to share with you about the NASA Quesst community survey campaign.

This talk summarizes the Quesst mission with emphasis on the community survey campaign and potential sources of response bias.

Background and overview



Community survey campaign



Potential sources of response bias

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NASA wants to change aviation by decreasing travel time.

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NASA invests in aeronautical technologies that are transformative, global, and sustainable. There's no question that getting there twice as fast would transform global aviation, but they key question is how to do it sustainably, with minimal impact to the environment.

NASA works with research agencies, companies, regulators, and academia toward a vision that supersonic travel can be made available to a broad spectrum of the traveling public. That can only occur if it is done sustainably.

Civilian supersonic flight over land banned 50 years ago, in 1973, because of loud sonic booms and the disturbance they cause to communities. While there are multiple environmental barriers to supersonic flight, NASA's Quesst mission focuses on mitigating the environmental impact of sonic boom, which NASA views as the key barrier to global supersonic flight. If supersonic flight is going to be global, it needs to operate both over land and over water.

By the way, a common misconception is that sonic booms occur just once during supersonic flight. That's not true—supersonic aircraft generate sonic booms along the entire supersonic route like the wake from a boat.

NASA's Quesst mission will generate key community response data needed to develop a noise standard for supersonic aircraft.

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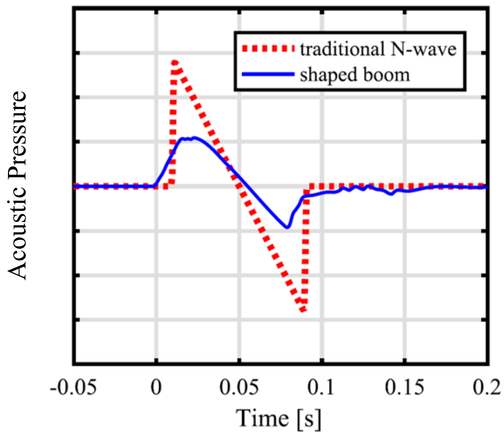
In order to replace the current ban, you need a new standard. You need proof of a new design approach, and most importantly you need community response data -- data that quantifies how people perceive low noise acoustic signatures.

While a lot of community response data was collected leading up to the ban, those noise levels were too loud to be remotely acceptable, so the data is not relevant for developing a new standard. The new data also needs to represent diverse communities.

Also, the data collection has to be done in cooperation with the international community. The key outcome of the Quesst mission is to collect and deliver data to the international regulatory community for their ongoing work to develop a new standard.

So, how do you design a low noise supersonic aircraft?

Aircraft shape is the key to reducing sonic boom noise levels at the ground.



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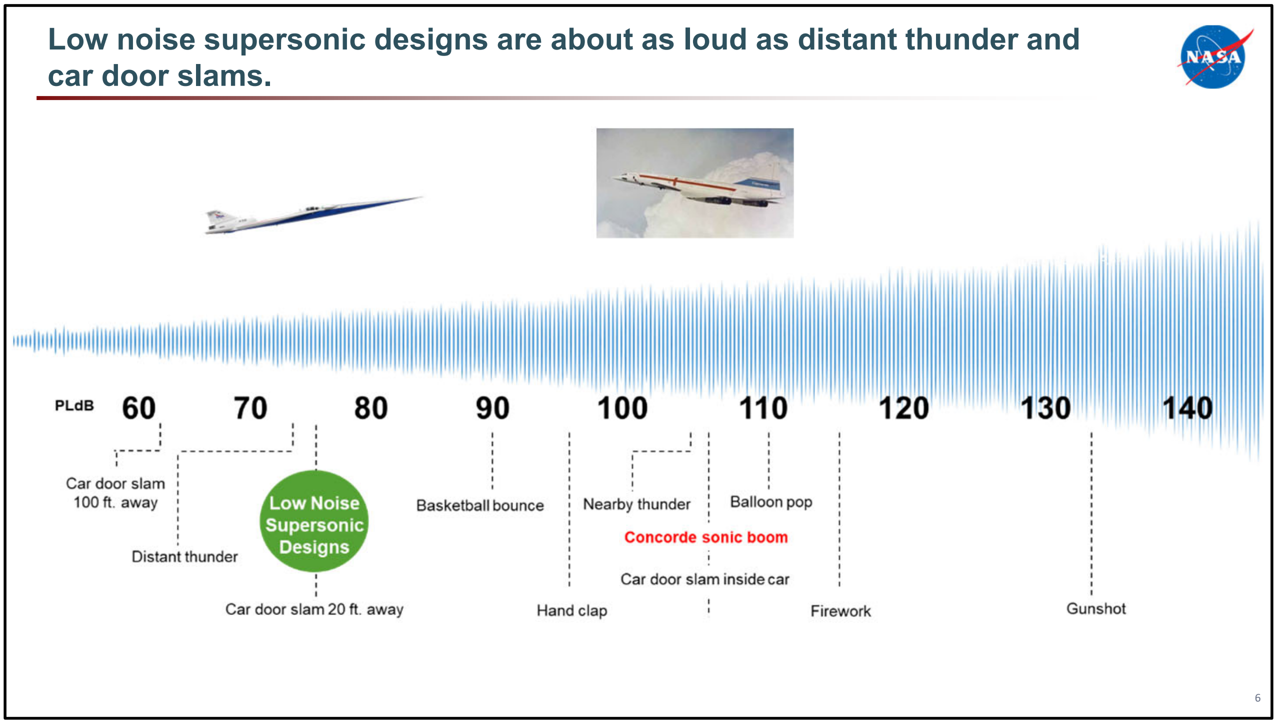
The answer is that it’s all in the shape. Aircraft shaping techniques to reduce sonic booms will be demonstrated by the X-59 for the first time in a clean-sheet, piloted aircraft.

An airplane traveling at supersonic speeds creates a system of shockwaves that merge together or pile up into two loud, explosive signals -- the signals shown in red above. It’s abrupt and very loud.

The key is to modify the flowfield so the wave don’t merge together or pile up, so the atmosphere can attenuate or smear each individual shockwave to a maximal amount. The rounded blue acoustic pressure signature is 40 dB lower in Perceived Level than the red signal.

These advances occurred over the past four decades due to better understanding of the phenomenon, better predictive tools, faster computers to iterate through hundreds and thousands of design options, as well as innovative and clever thinking.

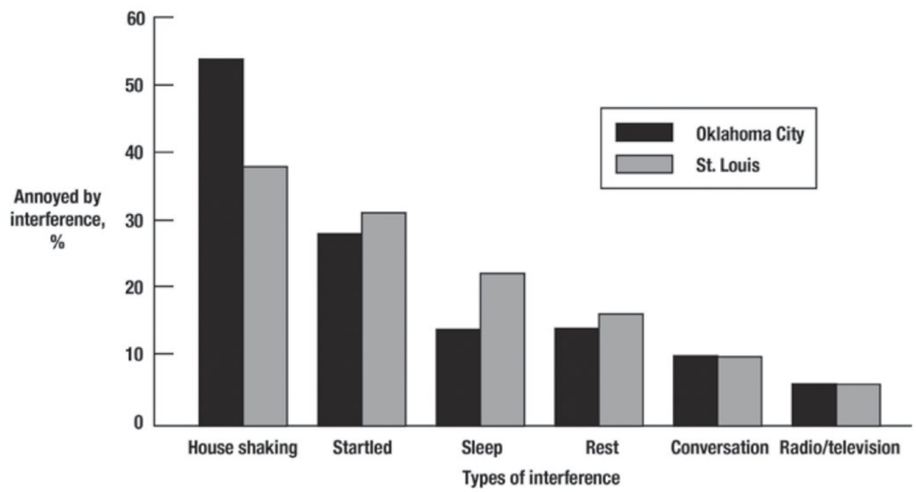
X-59 is designed to produce a waveform that is typical of future airliners.



For context, here is a scale of common sounds according to their decibel value on the Perceived Level scale. The red signal on the previous slide was Concorde at 105 dB Perceived Level, which is comparable to nearby thunder or a car door slam from inside the car. Thunder and door slams can be very startling when you are not expecting them.

By contrast, X-59's sonic thump is designed to be 75 dB, which is comparable to distant thunder, or a car door slam from across the street.

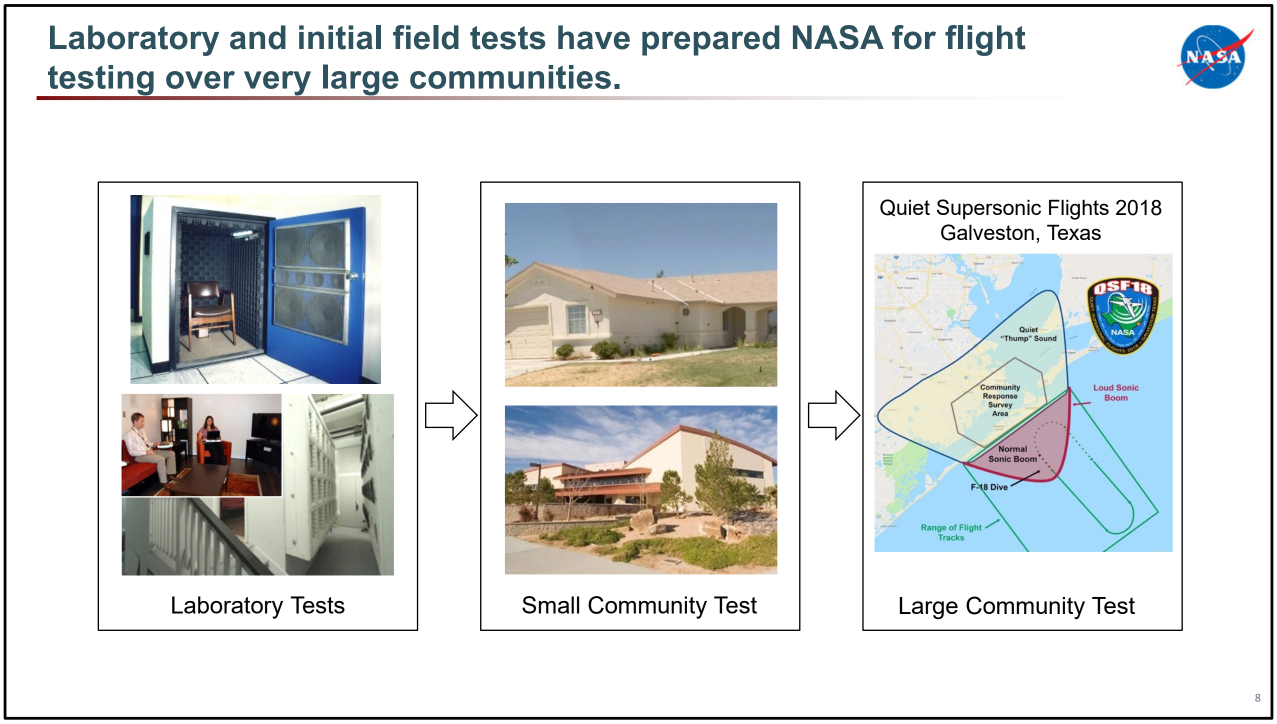
The key driver of non-acceptability from community tests in the 1960s was indoor annoyance.



In the 1960s two major community overflight tests occurred in St. Louis and Oklahoma City. Each test lasted half a year. In St. Louis there were 76 booms, and in Oklahoma city there were upwards of 1200 booms.

The results showed that conventional sonic booms would not be acceptable. An important result from the community overflights was that indoor annoyance was the key driver of nonacceptance.

Much careful research over the past several decades has alleviated some related concerns by showing that sonic booms pose no threat to other aircraft, do not harm animals, and, importantly, do not cause avalanches or earthquakes.



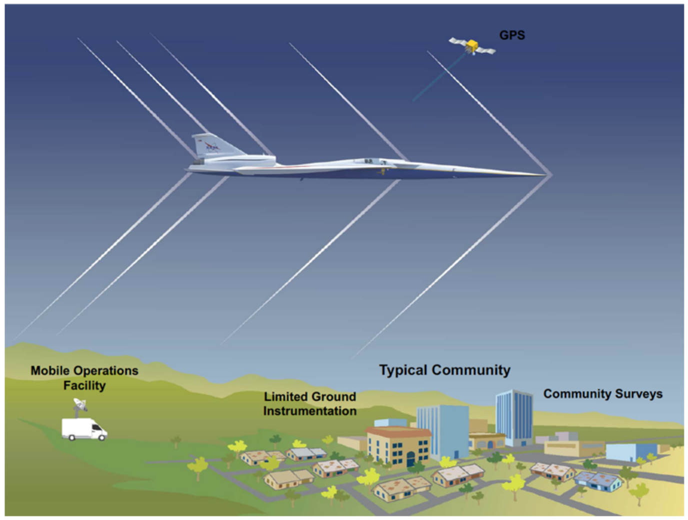
With indoor annoyance as the key concern, NASA's testing has shown in general that a threshold of acceptable noise may have been reached. This is the result of decades of testing with steadily increasing complexity, beginning with laboratory tests, then continuing in small communities and then a large community. Each incremental step has prepared NASA for the next step.

The lab facility at the top left is a concrete box that replays acoustic signatures as they would be experienced outdoors. Below that is a lab environment furnished like a living room for testing how people perceive sonic booms indoors. You can sort of see the wall of speakers that gets pushed against the wall to simulate the shock waves arriving outside the room. The lab environment is great because it's repeatable and you can create a lot of variation in the sound, but that control and repeatability comes at the cost of realism because it's not your living room, so your reaction may be different.

So, NASA went into the field to understand more about how people respond to low noise acoustic signatures in their own homes. NASA invented a maneuver using a conventional airplane. The airplane dives steeply and goes supersonic briefly to create a pulse of sonic boom that travels a long distance before the sound hits the ground. As it travels that long distance it gets some of the features of a low noise acoustic signature, like the decreased pressure amplitude and characteristic rounding. It's repeatable and variable. It creates a quiet sound in one location, but a loud sound in nearby locations. You can only do this in limited environments, like on base at Edwards Air Force Base, in the middle of nowhere.

In 2018, NASA got more daring and wanted to expand our knowledge of how to engage successfully with a community to conduct this testing. In Galveston, Texas, NASA found a community that is densely populated, but relatively isolated by being close to the water where NASA could place the loud sonic booms. This test gave NASA the opportunity to practice, engaging with community members, sharing airspace with other aircraft via coordination with air traffic control, making ground measurements of the acoustic signatures, and developing and deploying a web-based survey to hundreds of members of the public.

Community overflights with surveys are the most effective approach to assess community response.



The goal of the mission is to assess community response. How do you collect community response data?

Tens or hundreds of thousands of survey responses are needed from communities that vary in terms of geography, climate, building construction, and community demographics.

A range of exposures are required, including possibly conventional sonic boom levels.

A maximum of no more than 6-8 exposure per day for any one community is expected for the foreseeable future of supersonic flight.

The overflight campaign must last long enough to assess the effect of repeated exposures.

The work has to be done in conjunction with the international research and regulatory community to ensure acceptance of the results. Ideally the tests will be conducted both within the US and internationally.

To meet these requirements, a community overflight campaign is the most effective approach.

X-59 effectively meets requirements to replicate acoustic pressure signal of a larger supersonic aircraft while using normal commercial aircraft flight maneuvers.

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To accomplish community overflights, a noise source is needed, and that is X-59. The x-plane ideal is to define a problem, minimize the number of requirements, and create a system that meets those requirements effectively.

For X-59, the first main requirement is to effectively replicate the acoustic pressure signal of future, larger supersonic commercial aircraft. The second main requirement is to conduct community overflight tests using normal commercial aircraft flight maneuvers, so steady level flight rather than supersonic dives.

The shape is new and unique. You'll notice the long tapered noise, 3D shaping, unique propulsion integration, and it has about every type of tail surface imaginable. All these features that may be in a future supersonic airliner are in the X-59.

Other than this, it's assembled using as many existing parts as possible: GE-F414 engine, F-16 landing gear, T-38 aft canopy and ejection seat

You'll notice there's no window on the front. One of the new systems NASA brings is an external vision system that allows the airplane to be fully shaped and still provide the pilot with sufficient visibility for normal operations.

The airplane is 100 feet long, the length of a basketball court, and the nose itself is 38 feet long. The cruise speed is Mach 1.4, which is what we could get to from an existing engine. It's fast enough to eliminate transonic effects and get the data needed from supersonic operations. It will fly at a typical supersonic altitude of 55,000 ft.

The Quesst mission has three phases.

Phase 1—Aircraft Development

- Detailed Design
- Fabrication, Integration, Ground Test
- Checkout Flights
- Subsonic Envelope Expansion
- Supersonic Envelope Expansion

Phase 2—Acoustic Validation

- Near-, Mid-, Far-field Measurements
- Ground Measurements

Phase 3—Community Response

- Initial community response overflight study
- Multiple campaigns (up to 5) over representative communities and weather across the U.S.

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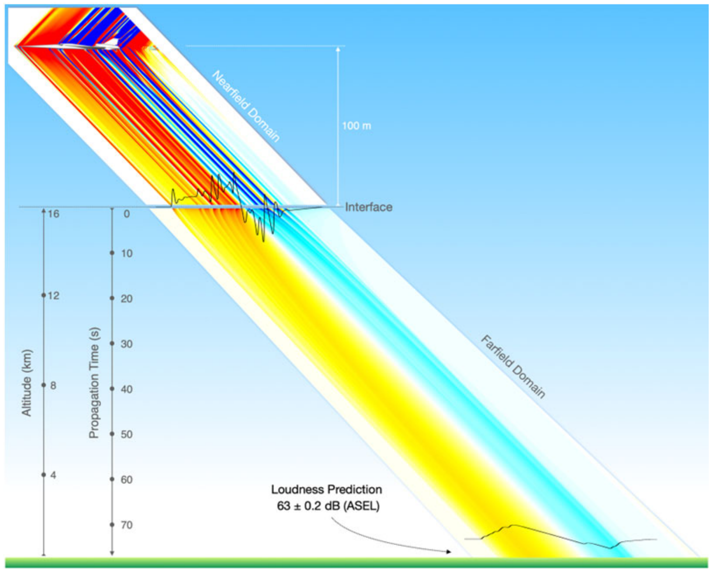
The Quesst mission consists of three phases. First is aircraft development, followed by acoustic validation and community response. We're currently in Phase 1, while planning is underway for Phases 2 and 3.

The goal of the acoustic validation phase is to validate NASA's prediction tools as well as X-59's acoustic signature.

Ground recording system unit



Shock sensing probe mounted on NASA F-15

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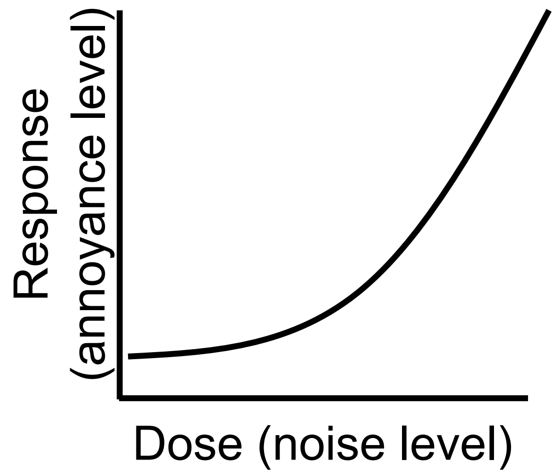
For the community reponse phase, in order to establish a dose-response relationship NASA must be able to estimate the sound exposure from X-59. This means predicting the system of shock waves near the airplane and how they travel to the ground. This also enables you to back out flight conditions such as altitude and trim are needed to produce a desired sound exposure over a given area.

The acoustic validation phase will take place around Edwards Air Force Base and NASA's Armstrong Flight Research Center. Validation measurements of acoustic pressure will be made at three key altitudes to validate NASA's prediction tools: near the airplane, then just above the earth's boundary layer where the pressure signature has evolved, but before the turbulence affects the pressure signature, and then finally on the ground. NASA has made each of these types of measurements in the past, but never on such a low intensity signal and never on such a large scale (30 mile ground array of microphones). The nearfield measurements are made with a probe on an F-15 that is chasing X-59. The measurements just above the Earth's boundary layer are made via a motorglider, and the measurements on the ground will be made using a state-of-the-art custom designed array of noise monitors.

The primary Quesst mission goal of generating dose-response data to assess community response will be achieved during the community response phase.



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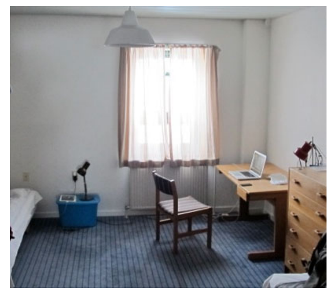
The key outcome of the community survey campaign is dose-response data.

The vertical axis is annoyance level, which is collected via a survey. The survey will be web-based, accessible via computer, mobile device, or via smart phone app. For historic reasons, the response is expressed in terms of percent highly annoyed, which I'll describe later.

The horizontal axis is dose or noise-level. Each survey response gets matched with a noise dose, a single-number rating that corresponds to sound level.

The secondary research goal is to collect survey data that aids interpretation of the dose-response data.



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In addition to the primary goal of defining a dose-response relationship, the secondary research goals are to collect data to help interpret dose-response results. These data will be gathered via survey questions.

- -effects of indoor rattle and vibration
- -effects of listening environment (home vs. work, indoor vs. outdoor, windows open vs. closed)
- -effects of time-of-day
- -prevalence of “startle” which was a major annoyance component in historic sonic boom studies

The survey questions below address dose-response data and help interpret results.

1. The thump occurred at approximately (TIME). Where were you at approximately (TIME)?
   - Home/Work/Somewhere else
2. (IF SOMEWHERE ELSE) Please enter your location at approximately (TIME). You can provide an approximate address, named location, e.g., a store or other landmark, or cross street
3. Did you hear a sonic thump that occurred at (TIME)? Y/N [If No, skip to 8]
4. **How much did the sonic thump bother, disturb, or annoy you?** →
5. Did the sonic thump startle you? Y/N
6. Vibration is motion. The motion may be seen, felt, or heard.
   Did you see, feel or hear vibration from the thump? Y/N
7. Rattle is a type of noise that can occur when objects move due to vibration.
   hear rattle from the thump? Y/N
8. Were you indoors or outdoors at (TIME)? Indoors/Outdoors
9. (If indoors) Was there at least one window open in the room at the time?
10. Please enter any additional comments

Annoyance
Not at all
Slightly
Moderately
Very
Extremely

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So now, we're going to walk through the survey questions we are currently considering for future X-59 community tests. These questions will be asked for each flyover event and an additional one at the end of the day, which means that over the course of a few weeks, participants could be responding to upwards of a hundred surveys.

The first question notifies an individual when the event happened as asks where they were at that time. They can choose home or work, or they can give an alternate location via address or map pin. The location will be used to determine the noise dose.

Next, they respond whether or not they heard the sonic thump event.

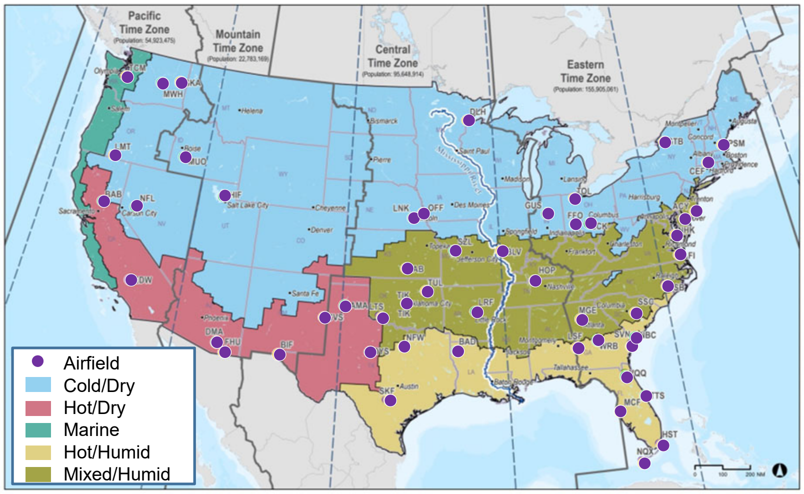
If no, they skip the response questions, but if yes, we go to the key question of "How much did the sonic thump bother, disturb, or annoy you?" to which they provide a response from the 5-point verbal scale. If the response is either "very" or "extremely", then it counts as "highly annoyed" while all other responses count as "not highly annoyed."

Additional data is collected, such as whether the thump startled them, whether they experienced vibration, which is motion that may be seen, felt, or heard, or heard rattle, which is a type of noise that can occur when objects move due to vibration.

Respondents are then asked about their environment, whether they were indoors or outdoors and if indoors, whether there were any windows open.

Lastly, any additional comments are requested.

NASA plans up to five social surveys in different geographic regions of the US.



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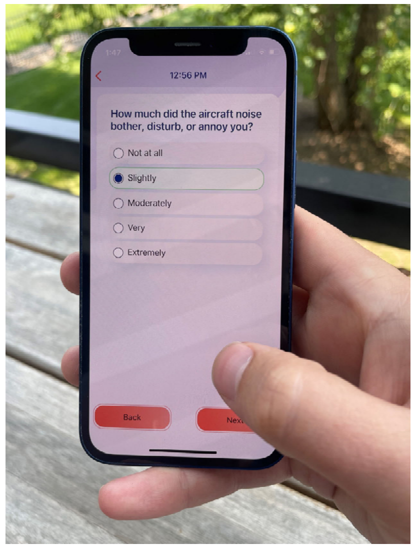
To collect representative data, NASA is planning up to five 1-month-long socio-acoustic surveys. To be representative, the test locations must span the various US geographic regions.

This chart shows approximately 4 dozen airfields that meet the X-59 operational requirements overlaid on the major US climate zones. From each airfield, a 600 sq n mi survey recruitment region will be selected to be overflown up to six times daily for a month. The month-long duration was chosen to give participants time to adjust to the new sounds.

The first test will be flown from NASA Armstrong / Edwards Air Force Base in southern California over a region to be determined. The subsequent airfields and recruitment regions have not yet been selected.

A minimum sample size of 1000 participants per region is currently planned.



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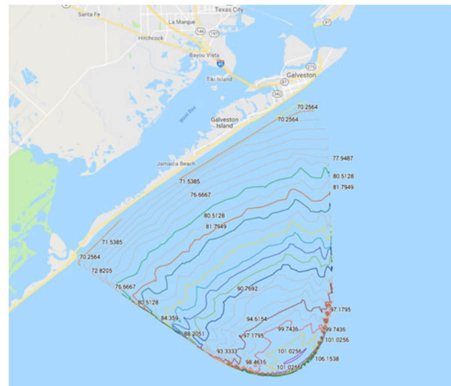
In each region, NASA intends to recruit a probability-based sample of 1000 participants. This sample size was selected to improve the stability of dose-response estimates based on survey data from a previous test. It will also enable representativeness in terms of diversity of age and socioeconomic status, although neither is expected to have a strong influence on dose-response. A month-long test of the survey process without X-59 overflights is currently underway with approximately 800 members of the public.

Noise exposure will be estimated via a combination of measurements and calculations.



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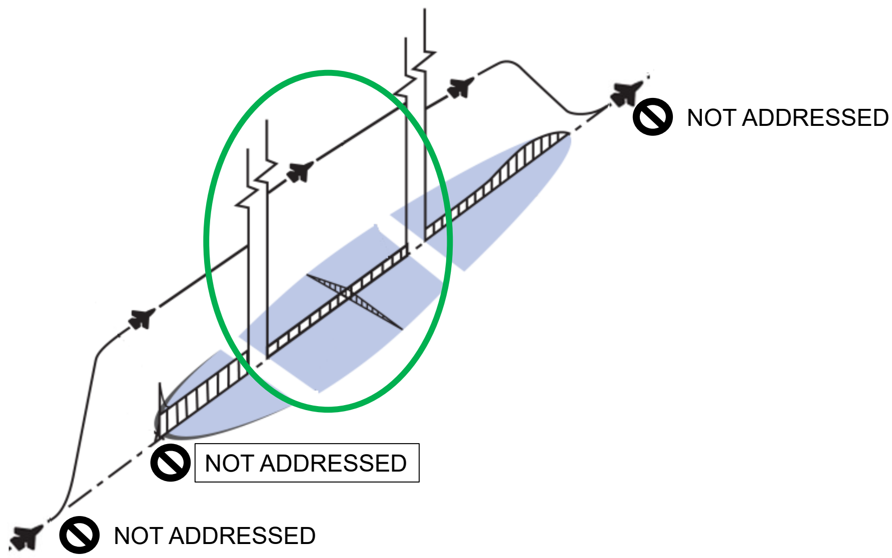
In order to assess dose-response, each survey response must be linked with the corresponding noise exposure. The noise exposure will be estimated via a combination of measurements (as shown here) and calculations.

In summary, our key challenges include:

- -the sparsity of noise monitors throughout the large communities (~150 monitors across 600 square miles)
- -extracting the low noise signals from ambient noise contamination
- -ensuring good estimates of uncertainty in both predictions and measurements

Our strategies to address these challenges include ambient noise correction methods and Kalman filter data assimilation techniques. All methods will be demonstrated during the acoustic validation phase.

The Quesst mission focuses on *human* response to *supersonic cruise* during *daylight* hours.



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The need to focus test objectives means that certain data will not be collected.

The effect of low noise supersonic overflights on animals will not be tested because adverse effects are not expected.

The mission focuses on supersonic cruise, not landing and takeoff noise.

Nighttime noise exposure cannot be tested in the current timeframe due to operational and safety considerations.

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 high altitude emissions and aircraft efficiency. NASA has active research programs in both areas.

The Quesst community survey campaign is scheduled to begin in 2026.

2019 - 2025	2026 - 2028	2027+
Planning Stage	*Execution Stage*	
• Develop overall Community Testing plans o Survey design o Exposure estimation o Operations o Public outreach and communication • Risk reduction activities o Survey test o Acoustic monitor and infrastructure checkout o Automated data processing validation • Obtain feedback on survey methods and exposure estimation approaches o ICAO CAEP Working Group 1 participation o Virtual and in-person international workshops o Independent review panel	• Community survey 1 near NASA Armstrong • Additional community tests o Various regions o Participant demographics • Survey and exposure data analysis • Develop dose-response relationship • Aggregate analyses and extend to nationally-representative database	***Data delivery to regulators***

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This slide shows the current schedule for the community survey campaign. Planning began in 2019 and continues through 2025. The survey campaign is currently planned for 2026 – 2028, which data delivery to regulators to begin in 2027.

The community response phase includes a support contract to aid all elements of planning and execution.

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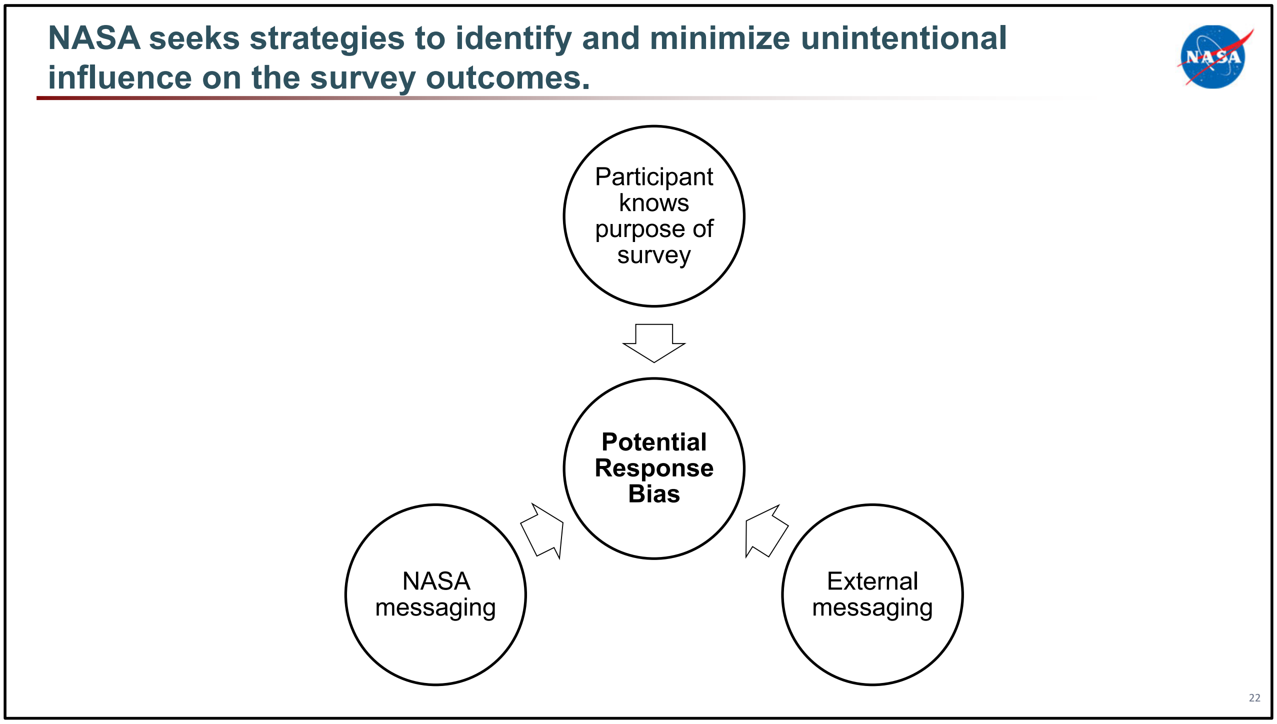
Build-out of joint government and industry team
- Multiple specialized subcontractors
- SME from US DOT Volpe Center
- Skillset overlaps to minimize gaps

Support contract to aid in all elements of planning and execution of community tests
- Community survey methods
- Acoustical and meteorological data collection and analysis
- Noise exposure planning and execution
- Combining survey and acoustical data
- Deployment activities

NASA technical roles
- Oversight and SME guidance to contractor team
- Complementary SME research related to Phase 3 community testing
- Identify, address, and mitigate technical gaps in as needed



Just as we need to avoid bias in our noise measurements, we also need to avoid it in the survey responses. Response bias refers to conditions or factors that cue survey participants to provide inaccurate or false answers.

There is a potential that knowing the purpose of the survey might lead to more extreme annoyance responses. Evidence *against* this phenomenon was collected in three separate noise annoyance surveys in the 1970s, but the potential remains.

NASA's messaging about the mission and the survey. NASA cannot obscure the intent of the survey, so it must maintain a balanced, objective tone. NASA's communications plan is being reviewed for objectivity by an Independent Survey Expert Panel.

Messaging from other sources such as news media and social media. NASA obviously cannot control this messaging, but it can monitor.

What concrete actions can identify and minimize response bias?

In summary, the Quesst mission focuses on overcoming the technical and regulatory barriers to low noise supersonic flight over land.

Quesstions?

For more information,
visit www.nasa.gov/quesst

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- The Quest mission is focused on overcoming the technical and regulatory barriers to quiet supersonic flight over land
- The development of a new supersonic X-plane is the core of the mission
- Preparation for acoustic validation and community survey phases are also progressing
- Near term focus is on completing an X-59 aircraft that is safe to fly in the National Airspace System and meets the mission performance goals.
- NASA is engaged with the FAA and ICAO in the development of an international standard for sound levels for supersonic overland flight.
- NASA seeks the broadest possible engagement with the international research and regulatory community to support acceptance of Quesst Results.
- The airplane may be cool, but it’s the data that’s important.