

Proceedings of Meetings on Acoustics

Volume 19, 2013

<http://acousticalsociety.org/>

ICA 2013 Montreal Montreal, Canada 2 - 7 June 2013

Noise

Session 2pNSa: Community Response to Low-Amplitude Sonic Booms

2pNSa3. A flight research overview of the Waveforms and Sonicboom Perception and Response Project, the National Aeronautics and Space Administration's pilot program for sonic boom community response research

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To support the National Aeronautics and Space Administration's (NASA)'s ongoing effort to bring supersonic commercial travel to the aerospace industry NASA, in cooperation with other government and industry organizations, conducted a flight research experiment to identify the methods, tools, and best practices for a large-scale sonic boom community human response test. The name of the project was Waveforms and Sonicboom Perception and Response (WSPR). Such tests go towards building a dataset that governing agencies like the Federal Aviation Administration and International Civil Aviation Organization will use to establish regulations for acceptable sound levels of overland sonic booms. This paper focuses on NASA's role in the project on essential elements of community response testing including recruitment, survey methods, instrumentation systems, flight planning and operations. Objectives of the testing included exposing a residential community with sonic boom doses designed to simulate those produced by the next generation of commercial supersonic aircraft. The sonic booms were recorded with an instrumentation array that spanned the community. Human response data was collected using multiple survey methods, and was correlated to acoustic metrics from the sonic booms. The project resulted in lessons-learned and the findings of appropriate methods necessary to implement a successful large-scale test.

Published by the Acoustical Society of America through the American Institute of Physics

INTRODUCTION AND MOTIVATION

Shortly after an aircraft broke the sound barrier in 1947, the vision of supersonic civilian transportation became more obtainable. This idea became reality and existed for many years in the form of the Concorde (British Aircraft Corporation, now BAE Systems, London, United Kingdom) and TU-144 (Tupolev, Moscow, Russia). However, those aircraft were only able to fly supersonic over oceans due to a land speed restriction to avoid the sonic boom created by a supersonic aircraft. Sonic booms can be loud and startling, so the noise problem on the ground was regulated by restricting aircraft speed to slower than the speed of sound. In a continued effort to develop commercial supersonic transportation, the aeronautics industry has been researching different shape designs of aircraft since it has a large influence on the waveform shape, magnitude, and human perception of the sonic boom.

Many studies have been conducted to examine the response of humans to various sonic boom waveforms, even so far as to study what metric to use as the “ruler” to correlate human reactions to incoming sonic boom waveforms. Sullivan gives a good synopsis of the history of sonic boom human response testing.¹ Recently, very small scale evaluations by “expert ears” have confirmed earlier studies² and suggested that single-event sonic boom noise levels not exceed 70-80 PLdB (outdoors) for viable community noise acceptance levels to support commercial supersonic aircraft over land. These levels are, by comparison to the Concorde and other supersonic military aircraft, quiet and are often referred to as “low booms.” The Waveform Sonicboom Perception and Response (WSPR) project was the National Aeronautics and Space Administration’s (NASA)’s most recent sonic boom community response effort, and the first to use these low booms.

The WSPR effort was conducted as part of the NASA Supersonics Project to serve as a pilot program to examine the impact of low booms generated from actual aircraft (not simulated) on people in their actual home living environment. WSPR also gathered data to examine the effectiveness of the data gathering and analysis methodologies used during the WSPR effort, and to identify strategies and address issues to minimize adaptation effects associated with introduction of a new noise source into a community. The project assumed that at a later date, a low boom demonstrator aircraft would be built to help examine the effects of and responses to shaped low booms on people. Until then, the WSPR effort was a first step to develop a methodology of how to conduct such a test to gather relevant community response data to low booms. In order to generate these levels, the experiment involved precision flight of an F-18 airplane (McDonnell Douglas, now The Boeing Company, Chicago, Illinois, USA), using what is referred to as a “Low Boom Dive.”³ The WSPR effort was a small-scale effort utilizing volunteer human response subjects from the Edwards Air Force Base (EAFB) (Edwards, California, USA) community.⁴ The data collected was not representative of the “average person,” as sonic booms are commonplace at EAFB.

This paper focuses on NASA’s role in the project on essential elements of community response testing including human response subject recruitment, the operational processes involved in implementing the surveys throughout the community, instrumentation systems, flight planning, and operations. Actual sonic boom human response results,⁵ survey methodology conclusions,⁶ and sonic boom analysis⁷ are presented separately.

TEST OBJECTIVES

The primary objective consisted of validating human response survey methods, data acquisition, analysis methods, Institutional Review Board (IRB) approval, and human response subject recruitment strategies for sonic boom human response research. WSPR intended to expose residential communities with sonic booms similar to those expected to be produced by next-generation commercial supersonic aircraft. These sonic booms were expected to have peak ranges from 0.13 psf to 0.53 psf while producing yearly averaged C-weighted day-night sound levels (CDNL) of 42 to 58 dB. A majority of the sonic booms were generated with the low boom dive maneuver. However, in order to get the desired CDNL levels there were also some “normal booms” planned, generated by a level supersonic pass. The conclusion was reached that the CDNL metric explains the most variation in annoyance compared to other metrics considered. The project would then measure both the sonic booms on the ground and sonic booms transmitted inside residential buildings. WSPR had an objective of coordinating and completing 20 to 25 flights over approximately 10 days. The aggressive flight phase consisted of only a two-week window.

Other objectives were to evaluate the recording quality and operational robustness of the sonic boom field kits (SBFK) instrumentation array, which is a sonic boom recording system capable of being spatially distributed over large areas. Both acoustic and subject response databases would be obtained to correlate aircraft flight conditions to a human’s response to sonic booms and the levels measured on the ground by the SBFK.

HUMAN RESPONSE SUBJECT OUTREACH AND RECRUITMENT

Conducting the test on a small, military-controlled community had both benefits and challenges. Some of the benefits included accurate, easily accessible demographical data and several exclusive chains of communication with residents. Some challenges consisted of privacy concerns for military residents, turnover rate, and requirement for approval of all communication with residents. All materials needed to be approved by EAFB, adding another time-consuming step to the process. Also, EAFB would not allow door-to-door solicitation. Therefore, the project had to make community-wide contact, and wait for interested residents to respond.

Ideally the project would have had human response subjects uniformly spread across the community, occupying various, but known, types of housing structures. Knowing the types of homes the subjects lived in is valuable since sonic booms have different effects on different structures.⁵ Being able to coordinate closely with EAFB allowed us to know the exact housing types within the area. All homes were stucco construction, and housing types consisted of duplex units and single-family detached homes. All of the two-story units were located together in the Junior Enlisted area of the community. There were 408 duplex units (about 10 of which were two-story), and 388 single-family detached homes (six of which were two-story). Also, projections of the occupancy rate and turnover of the community were obtained. These projections enabled the project to estimate the number of possible human response subjects available and anticipated attrition, which affected the time of year the test would be conducted.

Successful public outreach was necessary to recruit the 100 human response subjects desired for testing. The small, intimate nature of EAFB allowed communication exclusively with the community through multiple channels. Communication included electronic channels such as emails sent to all EAFB personnel and posts on EAFB social feeds such as Facebook, Twitter, and the EAFB website. First contact and solicitation to the community was around 19 weeks before the first test day, through the aforementioned electronic channels as well as an article in the EAFB newspaper. The second method of contact was through flyers and a letter sent to all homes on EAFB. The letters provided unanticipated challenges. Due to privacy concerns, EAFB would not allow non-military parties to have the names and addresses of residents. Therefore the project had to provide EAFB with the materials and let EAFB mail the materials out, which caused delays. A third round of contact included offering \$50 pre-paid gift cards as an incentive to participate.

At the conclusion of the project, an appreciation event was held for the human response subjects. The event served as an opportunity to give human response subjects an overall view of the project, early results, and the role they played. The appreciation event also served as an opportunity to distribute the incentives, hand out certificates of appreciation, and for the human response subjects to return any outstanding equipment or survey materials.

TEST PREPARATION

Before the WSPR flight phase there was a lot of test preparation. Preparation included testing and preparing the human response subject survey material, aircraft systems checks, and deploying support instrumentation.

Surveys and Pre-Test

The human response subjects were given four different methods to complete surveys. The method assigned to each subject was random. One survey was to be completed each time a human response subject heard a single sonic boom event, and a summary survey was to be completed at the end of each test day.

Two survey methods included the use of smartphone devices. An Apple iOS survey application was developed by the project and installed on each human response subject's personal Apple-compatible devices by a member of the team prior to the test. This installation was done "door-to-door" and included a brief tutorial. Similarly, a Google Android survey application was also developed. This application was pre-installed on project-furnished Droid 2 smartphones and distributed to human response subjects at a centralized meeting. Both smartphone methods transmitted completed surveys immediately via web or email protocols to a data collection server.

The third survey method used paper forms. Human response subjects assigned the paper forms were sent packets with the survey materials shortly before testing began. The human response subjects were instructed to complete the forms, put them in the envelopes, and drop into any United States Postal Service (USPS) mailbox. The fourth survey method used a web-based survey. Subjects assigned to the web were asked to complete the surveys on-line using their own personal computer. This web survey was designed to mirror the layout of the paper forms.

As a way to identify problems with the survey questionnaire or data collection procedures before they were used in a "real" study, a "pretest" was performed. The pretest was three days long, executed approximately 8 weeks

before testing, and included 21 participants. The participants were volunteer employees at the Dryden Flight Research Center (DFRC) (Edwards, California, USA). The pretest took place during normal business hours, and the participants were told to treat their office space as their home. Data from the pretest was not retained or analyzed other than to verify the data collection technologies execute correctly, and to identify potential trouble spots in question wording or response categories. The pretest included iOS, paper, and web-based survey methods. After the pretest, participants were contacted by telephone for a brief interview after all survey forms had been completed and returned. Participants were asked about the method of data collection, ease of use, wording of questions, appropriateness of response categories, and clarity of instructions. Some of the feedback provided from the pretest that was later used in WSPR included increasing the number of participants assigned to web-based over paper surveys to increase the ability to track data completeness, reviewing all data daily to facilitate participant follow-up if necessary, conduct more frequent follow-ups to ensure higher survey completion rates, and to develop tools or checklists to increase completion rates (for example, study calendars or daily task check-off lists).

Aircraft Air Data Calibration

The DFRC support aircraft fleet F-18 was used to support WSPR, of which usually two were required for each flight day and one as a dedicated backup. Accurate placement of the low boom sonic boom footprint on the community requires accurate knowledge of the Mach number and altitude of the aircraft, as well as consistent repetition of the low boom dive maneuver. Accurate Mach number and altitude would help eliminate off-condition passes, lending toward an aggressive, concise flight phase. The aircraft needed to be capable of performing at least six low boom dives in one flight. There was also a desire to utilize an aircraft that would allow the project to record accurate altitude, Mach, and positional data. The production aircraft airdata calibration has errors on the order of 0.045 Mach number in the supersonic region of interest. This error pertains to the difference between true and indicated Mach, and 0.045 Mach can result in up to 1.7 nm error in low boom sonic boom location.⁵ Since several F-18 aircraft were used during WSPR, the airdata calibration for each aircraft needed verification. Three aircraft (F-18A-843, F-18B-846, and F-18A-850) recently had undergone modification, the installation of a Traffic Collision Avoidance System (TCAS) antenna. The modification caused a change to the outer mold line near the airdata system, which could have potentially changed the aircraft's airdata position error. Also, pneumatic leaks in the pitot-static system can cause large errors in indicated Mach number and altitude; therefore, testing was performed to ensure the integrity of each aircraft system.

Three F-18 aircraft (F-18B-852, F-18B-846, and F-18A-850) were equipped with an Ashtech (Spectra Precision, Westminster, Colorado, USA) Z-12 Global Positioning System (GPS). The GPS data was post-processed after each flight to add in differential corrections from the Dryden base station. F-18A-843, used for five mission flights, was not equipped with an Ashtech Z-12 unit; thus, required the use of tracking radar. The radar data provided by the DFRC Western Aeronautics Test Range facility gave less accurate position information data compared to the Ashtech Z-12, but proved useful enough to be valid for sonic boom data analysis with diminished results. Additionally, F-18B-852 was equipped with an on-board instrumentation system, Research Quick Instrumentation Data System (RQIDS) and was used for four mission flights. RQIDS transmits aircraft state-parameter data (that is attitude, airspeed, position, pitch and roll rates, et cetera) to the DFRC control room. F-18A-850 was used for 13 mission flights while F-18B-846 was relegated as a spare.

The NASA F-18B-852 airplane has its 1553 bus data telemetered and recorded, and has carrier-phase differential GPS data available. Because this particular airplane is the only one of the group to have instrumented airdata, it was used as a reference pacer to compare to the other aircraft, as described in reference 5. One sortie was flown to verify the airdata calibration of each of the other three aircraft. In each case, the F-18B-852 flew in formation with each of the other aircraft. Altimetry methods using carrier-phase differential GPS for inertial position and velocities combined with GPS Radiosonde weather balloon data were used to compute true Mach number and altitude. The non-instrumented F-18 aircraft flew in formation with the F-18B-852 so both would have the same true Mach number and altitude. The pilot of the non-instrumented F-18 wrote down their airdata parameters that were displayed on the Heads Up Display (HUD) during stabilized formation flight.

The F-18A-843 and F-18A-850 data had a larger dispersion from the F-18B-852 data than the F-18B-846 data. However, the mean calibrations for each aircraft were comparable, and so the TCAS modification had no discernable effect on the supersonic Mach and altitude error of the aircraft.

Support Instrumentation

Atmospheric profile data for pre-flight mission planning and post-flight sonic boom analysis was gathered using an airborne weather measurement package consisting of a Lockheed Martin (Bethesda, Maryland, USA) LMS6 Radiosonde unit. The unit was able to measure temperature, relative humidity, pressure, wind direction, and wind speed derived from GPS differential measurement at a ground station and the Radiosonde. This package provided data from near-ground, up through the flight altitude of the aircraft. For ground level meteorological measurements, solar powered weather tower instrumentation suites that measured temperature, humidity, wind direction, wind speed, and pressure at GPS time-synced 0.5-second increments were placed within the residential communities.

Ground recording instrumentation was positioned within the residential and dormitory communities of EAFB. The locations were chosen to coincide with the residences of the approximately 100 human response subjects (figure 1a). The SBFK ground instrumentation array consisted of 13 individual field kits and repeaters. The array measured community exposure to sonic booms and was capable of capturing time-synchronous acoustic data across the entire EAFB human response subject area. As illustrated in figure 1b a field kit consists of a ground microphone that is solar powered with bi-directional wireless communication to a host station computer. Sensors were placed at specific locations of interest, particularly areas where human response subjects were densely located. In addition to the field kits, there were locations for two host stations and seven wireless signal repeaters. The SBFK was triggered at the host stations manually. The SBFK was contributed by Gulfstream Aerospace Corporation (Savannah, Georgia, USA) and Pennsylvania State University (University Park, Pennsylvania, USA), and have published details on their designs.⁸

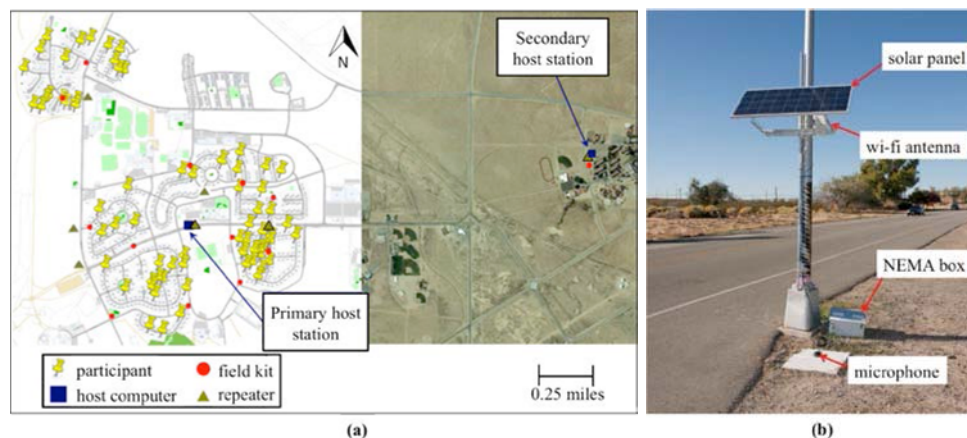


FIGURE 1. Sonic boom field kit system. (a) Layout (b) Field kit installation.

During the planning phase of the project, the team dedicated time to determining potential hazards, as well as mitigations to these hazards, to help ensure a successful test. While the team, comprised of operations personnel, engineers, and safety personnel, deemed there to be no hazards to human safety, the determination was made that there were significant hazards to mission assets, specifically field equipment. All of the team's concerns were traced back to damage or loss of field test equipment during unattended deployment. The three possible causes of equipment damage or loss were vandalism or theft, thunderstorm activity, and precipitation, all of which could result in loss of data or mission. Mitigations to the vandalism and theft hazards included securing the Wi-Fi antennas to utility poles at a height of 10 to 20 feet off of the ground, locking National Electrical Manufacturers Association-rated (NEMA) boxes and Supersonic Notification Of Overpressure Instrumentation (SNOOPI) to prevent unauthorized access; securing NEMA boxes to the base of each utility pole; briefing EAFB security personnel on the field test equipment deployment and locations; and labeling the NEMA boxes, SNOOPI, and weather towers with contact information. To mitigate the weather-related hazards all of the microphones were retrieved prior to any forecasted precipitation or thunderstorm activity, and the weather station was grounded. Lastly, there were visual checks of the equipment during non-flight test days and field testing of the equipment prior to flight operations.

For the WSPR project, human response subjects were asked to respond to all sonic boom events, both those generated by NASA aircraft as part of the program and by other military operations that normally occur at EAFB. The WSPR team had no advanced notice of these other military operations, so an automatic sonic boom recording system operating continuously for weeks during the WSPR test was desired. This device required protection from wind, rain, and dust. A solution was developed by using a NASA-developed Boom Amplitude and Shape Sensor (BASS)⁹ recorder and housing it inside a doghouse. The BASS employed a ring-buffer technique that kept a few

seconds of past data in memory. Once a sonic boom was detected, the contents of the ring buffer and additional data was recorded to capture pre-boom pressures as well as the entire boom signature. The BASS also used non-volatile compact flash card memory. A GPS receiver gave accurate time-tagging and geographic location information. The differential pressure sensor for the BASS was a SenSym SCXL004DN, which has a range of ± 20.8 psf and was mounted to the underside of the doghouse, facing downward. Since all this hardware was housed in an iconic doghouse, the acronym SNOOPI, or Supersonic Notification Of Overpressure Instrumentation, is used to describe this device. SNOOPI was deployed near the primary host station. The SenSym pressure transducer's location under SNOOPI sheltered it from dew, sprinkler water, and most of the wind.

TEST EXECUTION

Mission planning for WSPR followed the same technique as described in the Appendix of reference 10. In summary, a preflight GPS Radiosonde weather balloon was launched to gather the temperature and wind profile. A trajectory of a previously flown low-boom dive or level pass was used as a template, and adjustments were made for the current atmospheric conditions. The low boom dive (as shown in figure 2) was executed at 49,000 ft. pressure altitude, Mach 0.96. The aircraft then performed an inverted dive at -53-degree flight path angle, accelerated to Mach 1.10, and recovered straight and level at 34,000 ft. This data was then run through PCBoom,¹¹ a sonic boom propagation prediction computer package developed by Wyle Laboratories, to give a sonic boom footprint.

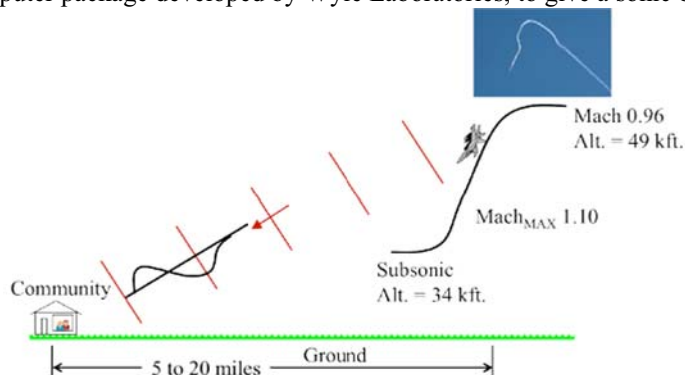


FIGURE 2. Low boom dive maneuver.

The design of the human response experiment gave the requested overpressure for the particular flight, and the F-18 waypoint was translated to place this overpressure at the center of the human response subject area. The Principal Investigator (PI) and most field personnel were positioned near primary host station (Host1), shown in figure 1a. This location served as the target point for the desired sonic boom overpressures. Individual microphones were also located at Host1 and provided real-time sonic boom data, allowing the PI to determine the actual overpressures generated. Once the PCBoom-derived sonic boom footprint was computed, the gradient of overpressure change as a function of distance downtrack of the waypoint was determined. If after a flight pass the measured overpressure was higher or lower than desired, the pilot was requested to shift his waypoint using the gradient to determine the amount of the shift required to place the target overpressure at Host1. Out of the 91 attempts to place a sonic boom on the community, 89 of them were successful, resulting in a sonic boom recorded at Host1. Of the 84 attempts to place a low boom, nearly 70% of them resulted in overpressures within 0.1 psf of the desired value. The flight crew and project team performed 22 flights from November 4–18, 2011.

DFRC control rooms were used for all WSPR flights. The control room was mission critical to establish ground-to-aircraft communication for the execution of test points, the ordering of test points, recording of real-time flight data, and aircrew situational awareness. A Mission Controller (MC) was the person responsible for the execution of the mission and the sole communicator between the control room and mission aircraft. All control room calls were made to the MC for transmission to the pilot-in-command. This single point of contact between the mission aircraft and the control room prevented the aircrew from being exposed to unnecessary chatter and potential confusion due to multiple calls from the ground. A Communications Relay person served as a communication path between Host1 and the MC using a push-to-talk (PTT) cell phone network. They captured important mission data and assisted the MC with waypoint updates and execution calls.

CONCLUSIONS: CHALLENGES AND LESSONS LEARNED

The methodologies developed during WSPR have helped shape the testing that will be required for any change-to-come to the current standing regulations of Mach number over land. A scaled-up version of the WSPR effort is desired and will be discussed in the Future Considerations section. WSPR provided a wealth of lessons learned that might apply to future similar operations and are detailed below.

Recruitment and Smartphones

An unforeseen challenge was getting the human response subject solicitation letters officially endorsed by NASA. EAFB would only allow the letters to be distributed if NASA, showing official support, endorsed them. However, only days before the anticipated distribution of the letters, DFRC management and Legal became reluctant to endorse such a letter without approval from the highest levels at EAFB. The project saw a two-week delay as it coordinated approval between DFRC management and the EAFB installation commander and General, who incidentally endorsed a separate, supportive letter of his own.

Also, during the early stages of recruitment and outreach planning it was thought that that incentives would not be needed to attract human response subjects because of the great working partnership and interest from the EAFB community. And there could be no raffle-like prizes for volunteers because it would be perceived as gambling on a military base. However, while there was strong interest within the community after the initial outreach actions, the project failed to meet its target of 100 human response subjects by about 30%. The target of 100 subjects was out of approximately 650 households on EAFB. The determination was made that \$50 pre-paid debit cards would be offered as an incentive for all human response subjects that participated through the end of the test. Six weeks before testing, a second phase of electronic outreach and another newspaper post were distributed to reflect the incentive. To avoid possible legal complications, the incentives were funded through the project's primary contractor.

DFRC's primary roles related to the smartphones that were used as a human response surveying method, were helping facilitate the installation of the surveying software on human response subjects' Apple iOS devices, and the distribution and collection of the Android phones. The greatest challenge was related to the Android phones, used by approximately 50 of the human response subjects. Because of the varying personal schedules and availability of the human response subjects, it was not possible to distribute all of the phones at one time. Seven separate meetings were required to distribute the 50 phones. It would have been greatly desired to maximize participation at these meetings. The human response subjects needed to be trained on the phones and briefed on their role in the project, therefore, distributing the phones individually (that is door-to-door or via mail) would have taken a considerable amount of time. The only suggestion by the project to improve this process for similar, future tests is to plan and schedule the distribution and briefing well in advance in an effort to get maximum attendance. Or, the phones could have been distributed individually, and the human response subjects given a tutorial video to watch.

Another challenge with the Android phones was collecting them at the conclusion of the test. The human response subjects were not to receive their participation incentives unless their phone was returned. However, two of the subjects were able to get theirs prior to returning their phone. Unsurprisingly, this led to a nearly one-month long process of collecting the phones back. The method used to manage the return of the phones was a simple paper check-off list. For a future, larger-scale test a more sophisticated, reliable system will need to be used to manage the collection of any hardware and distribution of incentives.

Support Instrumentation

The biggest challenge of using SNOOPI was guarding against false triggers due to wind. For WSPR, SNOOPI was placed in the middle of an open field. On a high wind day early in the WSPR project, in which the trigger threshold was set to 0.3 psf, 226 wind events were recorded. If set to 0.4 psf 75% of these wind events would have been rejected, and for a setting of 0.5 psf 95% would have been rejected. Therefore, when the winds were predicted to be high the threshold value of SNOOPI was set to 0.5 psf.

The SBFK provided several challenges since they were installed on a secured military installation. Because they were installed in the residential area of an Air Force Base, the project had to go through several layers of approval. Namely, the installation of the SBFK needed approval from the EAFB Space Utilization committee, EAFB Safety, and Base radio Frequency Management. The Space Utilization committee determines how all property and buildings on the Base are used. The committee had to be assured that the installation of the SBFK would not impede normal EAFB operations or affect residential services.

Lessons learned regarding deployment of the SBFK include needing to have accurate description (size, weight, accessibility needs, et cetera) of the hardware and comprehensive documentation of all installation specifications. When initially meeting with the appropriate EAFB approval committees, these details were limited and the approval process was delayed. For example, the original design height of the solar panel was too low from a safety aspect. Therefore, additional wiring and re-installations were necessary to raise them to an acceptable level. Also, since no dry-run installation was done, the time required to install the SBFK was unknown and greatly underestimated. Furthermore, the project team originally assumed they could work anytime of day necessary to complete the installations, however, EAFB limited work hours to daylight hours. This assumption posed potential threats to the schedule. To mitigate these threats, additional manpower was recruited.

Scheduling the times to launch weather balloons proved to be a challenge. Preflight weather balloon data was input into PCBoom to determine the waypoints for the F-18 aircraft in order to boom an exact area on the ground (Host1). Ideally every flight would have its own weather balloon launched at takeoff to capture exact conditions for post flight analysis. A normal balloon flight takes two hours to complete and only one balloon could fly at a time. When an F-18 aircraft flew twice within a two-hour window the same balloon data was used for both, having been launched halfway between the takeoff times for each F-18 aircraft. The same approach was used when other missions on EAFB requested a balloon launched within two hours of the WSPR project.

Some weather balloons occasionally terminated early prior to reaching the maximum altitude of the F-18 aircraft. To fill in the data gap, previous balloon data was inserted from the termination point to the altitude required for preflight planning or post flight analysis. This method was making an unlikely assumption that the weather had not changed since the previous balloon flight. Future flight research will have to address a standardized technique for this occurrence. Despite these challenges, no flight was unsuccessful due to loss of weather data.

Communications

The ability to communicate amongst field personnel, as well as between Host1 and the control room was crucial to the mission's success on many levels. The field personnel had to communicate with each other during daily microphone calibrations. Communication between the field personnel prior to the flight proved to be beneficial for troubleshooting hardware issues. Just prior to the flight operation, Host1 would provide the control room with a status update, while the control room would keep the field personnel updated on the mission's flight status. During the mission, the control room provided calls to Host1 two minutes prior the dive, and again at thirty seconds prior to the dive. After the boom, Host1 communicated whether or not the boom was heard, the overpressure of the boom, and any resulting changes to the following test point.

The aforementioned communications were facilitated by the use of a Push to Talk (PTT) network. While these radios were invaluable to mission success, the employment of them was not flawless. First, the phones themselves did not always function properly: there were many instances of communications impeded by a lack of signal or an exceptionally poor signal and the phones occasionally froze. Secondly, there were several instances of operational error. In hindsight, the lack of signal coverage should have been discussed in advance of the test, as this is a common problem with cell phones in the EAFB area, to facilitate a discussion concerning phone failure mitigation; these mitigations could have proved useful in instances of operation error. Early on in the flight-test phase, the discovery was made that the operator errors stemmed mostly from over-talking and a lack of training. A brief training session on the features and use of the phones, including basic radio communication etiquette, could have prevented most of these operator errors.

While these communication issues significantly impacted three flights, the team was able to overcome these difficulties fairly easily. The low boom dive maneuver created very visible and unique contrail shapes, allowing the field personnel to visually identify when the aircraft reached the test waypoint. The visual contrails, combined with communicating the sonic boom propagation time to Host1, allowed the field personnel to prepare for the oncoming boom and determine whether or not the boom reached the ground.

Mission Planning and Flight Operations

For the most part, the mission planning for WSPR went according to plan, and sonic booms were generated that were well within what the experiment design called for. One difficulty occurred for a normal boom run that needed to be run from west to east for the winds aloft of that day. The run placed the F-18 aircraft outside the normal military restricted area and in an area controlled by civilian air traffic controllers for the acceleration to supersonic speeds. Because of the production system pitot-static errors discussed in the Aircraft Air Data Calibration section,

when the aircraft accelerates from subsonic to supersonic, the indicated altitude (which is what the air traffic controller sees) takes dramatic climbs and descents in excess of 1000 ft. The air traffic controller cleared the F-18 aircraft to accelerate at a constant altitude, which the pilot did, but the pitot-static errors made it look like he was on an extreme rollercoaster ride through the sky. The misconception caused the controllers who are not used to supersonic aircraft much consternation.

A big challenge encountered during the WSPR flight campaign was the intense flight schedule. The flight schedule was purposely built to be pseudo-random, which meant flights could have taken off anytime throughout the mission day over a two-week period. Therefore, flexibility in asset and personnel availability was paramount.

FUTURE CONSIDERATIONS

The speculation can be made that sometime in the near future the international airspace will once again have supersonic civilian aircraft flying through it. The WSPR effort was never meant to provide all the answers, but to push further open the door to catch a glimpse into what problems might arise in future sonic boom community response testing. Therefore, further work is needed beyond the conclusion of WSPR.

The low-boom dive maneuver enabled execution of the first repeatable and predictable low magnitude shockwave community test. The results and lessons learned from the WSPR effort suggest that a similar test could be conducted on a community that is not accustomed to hearing sonic booms, unlike the EAFB community. Current plans call for future tests utilizing the low boom dive maneuver to evaluate the response of a larger scale community, which is unaccustomed to hearing sonic booms, to low magnitude sonic booms. These tests would likely need to be conducted over multiple diverse areas significantly different than the EAFB community, like areas with higher humidity or more urban environments.

Furthermore, a leading assumption in the Supersonics community is that the model for supersonic civil transportation will utilize shaped low-boom vehicle designs. The proposed major validation of the concept will be to build and demonstrate a large-scale shaped low-boom vehicle X-plane. The previously mentioned larger scale community response tests that utilized a low boom dive maneuver would then be followed by a flight campaign using this X-plane. Such a demonstrator would be flown to gather community response data of a low-boom shaped vehicle in all phases of flight. The data gathered during the testing of this aircraft would then be used to validate exposure prediction tools. It would also provide a body of data for regulators to evaluate for a possible rule change, allowing the opening of a whole new market for overland civilian supersonic transportation.

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