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2pNSa4. Objective data collection and analysis for the waveform and sonic boom perception and response program (WSPR)

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The Waveform and Sonic boom Perception and Response (WSPR) program experiment was conducted in November 2011. Low-amplitude sonic booms were created by planned NASA F-18 supersonic flights executing a unique dive maneuver. The WSPR program was designed to simultaneously collect objective sonic boom acoustic data and subjective response data from residents in the Edwards Air Force Base residential community. Sonic Boom field kits were developed for the WSPR program consisting of a digital data acquisition system with networked nodes, deployable for extended periods of time. The Sonic Boom Unattended Data Acquisition System (SBUDAS) purposely developed for sonic boom community noise testing was deployed and details of the measurement system and all aspects of the objective data collection process are described. Data analysis during testing provided vital information to the flight planners for experimental execution. This paper also explains the post-experimental analysis of the objective data achieved by creation of a measurement data archive, predictions of sonic boom exposure at subject household locations, an automated algorithm to locate sonic booms within the recorded data and computation of a variety of indoor and outdoor metrics.

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OVERVIEW

The Waveform and Sonic boom Perception and Response (WSPR) program experiment was conducted November 4 - 18, 2011 at Edwards Air Force Base. Low-amplitude sonic booms were generated by planned NASA F-18 supersonic flights executing a unique dive maneuver. The WSPR program was designed to simultaneously collect objective sonic boom acoustic data and subjective response data from residents in the Edwards Air Force Base residential community. Sonic Boom field kits were originally developed by Gulfstream, independent of the WSPR project to explore the potential of a remotely operated data acquisition system. WSPR provided an opportunity to deploy the units in a real-world sonic boom test scenario enabling the strengths and weaknesses of the system and user interface to be evaluated. The field kits consist of a digital data acquisition system with networked nodes, and are deployable for extended periods of time. The Sonic Boom Unattended Data Acquisition System (SBUDAS), specifically developed for sonic boom community noise testing, was deployed to acquire acoustic data for the WSPR experiment. Details of the measurement system and all aspects of the objective data collection process are described. Data analysis during testing provided vital information to the flight planners for experimental execution. This paper also highlights the post-experimental analysis methodology of the objective data. Specifically addressed are the prediction of sonic boom exposure at household locations, an algorithm to locate sonic booms within the recorded data and computation of several indoor and outdoor metrics.

SBUDAS ARCHITECTURE

The SBUDAS architecture is based on a host-node format. Each node was configured with two microphones with windscreens, a preamplifier, a National Instruments CompactRIO (cRIO) with the ability to log microphone data, ground boards and a battery; all of which were packaged into an environmental enclosure (Fig. 1). The nodes also had a solar panel and a wireless Ethernet bridge. The microphone orientation was such that the sonic boom was incident to the microphone diaphragm at grazing angle. Additionally, each node was GPS time-synchronized, allowing absolute time-correlation of the recorded data to other test parameters.
Each node was weather-proofed and utilized a solar panel and battery to provide continuous power permitting deployment without requiring grid power or frequent battery exchanges. The system was monitored and controlled remotely from a host computer with communications implemented via long-range wireless TCP/IP with nodal deployment extending across approximately 1.5 square miles. Outside of scheduled flights, the SBUDAS system was left in an auto-trigger mode in an effort to capture sonic booms generated by non-WSPR aircraft.
Figure 2. Microphone locations (field kit nodes), wireless repeaters, and host computers with respect to the Edwards housing community and test participants (Secondary array not shown).

Acoustic Array

The acoustic array was spread across the main housing neighborhoods in Edwards Air Force Base. Figure 2 is a graphical layout of the microphone (field kit) locations, the wireless repeater locations and the host computers relative to the Edwards housing area. The location of the field kit nodes was determined by two main factors: location of the human subjects and performance of the wireless communication hardware. Reliable communication along the transmission path between the host computer and any particular field kit was essential. The location of the primary host computer was chosen due to its centralized proximity to most of the human subject locations. The wireless repeater locations were chosen based on the performance of the wireless networking hardware. Development testing of the field kit array showed the reliability of the wireless communication was highly dependent on line of sight between any two components of the wireless network. The elevation of the broadcast antennae was also significant in the communication range between components in the wireless network. Additionally, development testing showed that the number of repeaters should not exceed three “hops” in the communication chain to ensure reliable connectivity. Based on the above constraints, the repeater locations were determined to provide field kit deployment across the extent of the housing community while keeping the networking components within their performance capability. This resulted in spacing between networking components that varied between 0.1 to 0.5 miles. The distance between the main housing area and the residential apartments (or dorms) exceeded the wireless range capability of the field kit array components, both in the range of a single wireless component and in the number of repeaters that could be deployed within that distance. A secondary host computer was directly connected to a field kit located adjacent to the apartment parking lot and ensured reliable data acquisition at that location.
POST-EXPERIMENTAL ANALYSIS

110 acoustic “events” were identified as sonic booms that ensonified the Edwards AFB housing community during the WSPR test. For the purposes of the WSPR test, an “event” was defined as a single plane’s sonic boom and was identified using field logs and recordings. The analysis of the event includes the first sonic boom received from a single plane’s fly-by. The recorded post-focus U-waves were not included in the metric analysis.

There were several non-WSPR related sonic boom events that were not recorded by the array of noise monitors deployed in the community for this study. For instances where the noise monitors did not record an event, a substitution was used to account for the exposure to the community. This was accomplished by identifying the field reported estimate of the peak overpressure of an event and selecting a sonic boom that was recorded by a monitor with a similar peak overpressure. In this case all substitution metrics were taken from the noise monitor deployed closest to the center of the housing community.

The program used for most of the analysis was “ADLOUD” developed at NASA Langley [Shepherd and Sullivan, 1991]. The output of the program computed loudness levels for a variety of acoustic metrics typically used for determining sonic boom loudness: the peak pressure level, the Stevens Mark VII Perceived Loudness, the A-, C- and un-weighted sound exposure levels, the Zwicker loudness, and the Perceived Noise Level. Details for each of the metrics are found in the reference [Page, 2012]. An excerpt of each recorded event was analyzed consisting of a 650 ms time window in the vicinity of the sonic boom that was tapered at the first and last 100 ms. Ambient levels were logarithmically subtracted from the computed metric level when the A-weighted Sound Exposure Level (SEL) was at least 1 dB less than the A-weighted SEL of the sonic boom. If the ambient levels were not at least 1 dB less than the metric level, the particular recording was considered to be too influenced by the ambient noise to include in the analysis.

The event excerpt was resampled to 32,000 samples/second and written to a wave file for computing the Moore and Glasberg metrics [Glasberg and Moore, 2002]. The program “TVL” is available on Dr. Moore's website1 and requires a specific input sample rate. The output of Moore's program is a time history of six metrics consisting of variations of the Sones and Phons. The time history had a resolution of 1 ms, and the six metrics were values of Moore & Glasberg's metric for three time averages – instantaneous, short-term and long-term – and two units – Phons and Sones. The maximum value of each of these time histories was captured and incorporated in the metrics files of the noise monitors.

Relationships between metrics measured indoors and outdoors of a typical house in the EAFB community were established during the House VIBES II measurements conducted by NASA [Klos, 2008]. An estimate of the exposure and peak overpressure metrics inside the homes was created using a linear regression of all the microphones deployed in the house versus a microphone outside the house. These regressions were used to estimate indoor metric levels for all WSPR subject house locations.

An inverse-distance weighting method [Shepard, 1968] was employed for estimating the metrics at the addresses of the human subjects in the community from the monitors. The metric, $u$, desired at an address located at position, $x$, was found using Eq. (1):

$$u(x) = \sum_{i=0}^{N} \frac{w_i(x)u_i}{\sum_{j=0}^{N} w_j(x)}$$

(1)

where $u_i$ is the metric at the $i$-th monitor and $w_i$ is weighting function given by Eq. (2):

$$w_i = \frac{1}{d(x,x_i)^P}$$

(2)

1 http://hearing.psychol.cam.ac.uk/Demos/demos.html.
The distance between the address location denoted by \( x \) and the monitor location is denoted as \( d(x, x_i) \). The power parameter, \( p \), is used to mimic the effects of turbulence on sonic boom propagation. As noted in prior Shaped Sonic Boom Demonstration (SSBD) measurements [Plotkin, 2005], turbulence effects can be seen at one monitor, while no evidence of the effect is seen at adjacent monitors spaced 500 feet away on a linear array. An example of the maximum overpressure predicted on a grid laid over the housing community is shown in Fig. 3. The maxima and minima show the locations of some of the noise monitors. The monitors that recorded the ‘average’ overpressure are difficult to identify, but the use of a power parameter of 0.5 in this figure shows how the peaks on the left side of the graphic exhibit signs of turbulent peaking and are limited to the area around the monitor. While the peaks are factored into the metrics predicted in the community as a whole, they have the most effect in the area around them. After studying various values of \( p \), the value of 0.5 was selected to characterize the behavior seen in the field in terms of the extent of geometric influence of the turbulent peak.

Figure 3. Peak overpressure (psf) from sonic boom sequence 68 predicted on a grid spanning the Edwards community.

Automated Boom Finder (ABF) Methodology for Low-Amplitude Sonic Booms

An Automated Boom Finder (ABF) methodology was developed for low-amplitude sonic booms such as those recorded during the WSPR experiment. Previously, sonic booms were identified visually in a recording by plotting the data in the recorded file and looking for the N-wave shape characteristic of a sonic boom. While higher amplitude booms can easily be found by employing an algorithm that uses an amplitude-based trigger to find when a recording exceeds some preset amplitude, the number of false triggers will increase as the trigger amplitude is decreased. Additional characteristics of the recording are examined in order to decrease the number of false triggers. Also sharp rise times are not unique to sonic booms (lightning, etc.), so analyzing frequency content versus time allows booms to be separated from other noise sources.

The boom identification stage in ABF utilizes a combination of amplitude triggering directly from the input data record and from a band-pass filtered version of the data. The first employs the triggering mechanism found in NASA Dryden’s Boom Amplitude and Shape Sensor (BASS) recorder. The algorithm compares a running sum of part of the sonic boom signature against a time-delayed sum of the same length. If the first sum exceeds the second by a set amount over a pre-defined length of time, then a “trigger” is set (Fig. 4). A band pass filter of 4-10 Hz is sufficient to capture the typical fundamental frequency of most sonic booms; however, this band pass filter range can be customized, as required, in the ABF program. If the aforementioned “trigger” is set, then the bandpass filter step is tested to determine if the absolute value of the bandpass filtered level exceeds a pre-defined threshold over the expected sonic boom interval from the time of the trigger (Fig. 5). By testing this filtered version of the recorded data for an exceeded level, the shape of the boom is implicitly sought and the sonic boom event is confirmed.
Figure 4. Time histories of the arrays in the trigger functions.

Figure 5. Graph showing boom record with its band-passed filter trace overlaid as a dashed line.
LESSONS LEARNED AND FUTURE WORK

Preparations for follow-on human subjective response testing should include determining an appropriate microphone density for the community under test. An additional consideration for future testing would be to determine the field kit resources required to support any follow on testing. There are certain components of the field kits that will readily scale with an increase in the number of system nodes. For example, the primary field kit hardware (batteries, microphones, solar panels, etc.) will readily scale. However, the infrastructure for both long range and short range communication may or may not scale depending on the means of implementation. Future plans for field kit development include remote access and control of the measurement hardware. Consequently, the intended command and control of the data acquisition system would support any required augmentation of the field kit nodes relative to the number of nodes used for the WSFPR test. Future plans for field kit development also include noise metric calculations at each field kit to provide near “real-time” feedback of sonic boom levels. This would facilitate real-time feedback to the flight plan for changing the exposure/dosage of the human subjects, potentially allowing closer agreement to the target levels desired for each day/period of testing.

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REFERENCES