Project 007 Civil, supersonic over-flight, sonic boom (noise) standards development

The Pennsylvania State University

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- Period of Performance: August 4, 2014 to July 31, 2016
- Task(s):
  1. Study of Variability Effects

The Pennsylvania State University

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- FAA Award No.: 13-C-AJFE-PSU Amendments 004, 014, 026
- Period of Performance: August 4, 2014 to December 31, 2016
- Task(s):
  2. Community Instrumentation and Monitoring

Project Funding Level

This project supports the Civil Supersonics Overflight Sonic Boom (Noise) Standards Development through research conducted on multiple tasks at the Penn State University. FAA funding to Penn State in 2015-2016 was $200,000 comprised of $50K to Task 1 and $150K to Task 2.

In-kind cost sharing was provided by Gulfstream Aerospace Corporation in July 2016 to Penn State in excess of $200K. The point of contact for this cost sharing is Mr. Robbie Cowart, robbie.cowart@gulfstream.com . The Penn State Applied Research Laboratory also provided substantial in-kind cost share to Project 7.

Investigation Team

For 2015-2016 the investigation team included:
Penn State
Victor W. Sparrow (Co-PI) (Task 1)
Kathleen K. Hodgdon (Co-PI) (Task 2)
Researcher: John Morgan R&D Engineer (Task 2)
Researcher: Bernard Kozykowski R&D Engineer (Task 2)
ARL Graduate Research Assistant Will Doebler (Task 1: variability effects investigation)
ARL co-administered PSU Scholarship for Service undergraduate student Mitch Gold (Task 2: Community Monitoring)

Project Overview

Currently, the FAA is participating in ICAO CAEP effort to formulate new civil, supersonic aircraft sonic boom (noise) certification standard. To achieve this, CAEP Working Group 1 is addressing the sonic boom phenomenon, the signal acquisition and analysis of boom and making vibro-acoustical analyses and correlations with human response. This effort relies on extensive research being conducted to define the aircraft design and its performance. Equally important are ongoing efforts designed to better understand the subjective acoustical annoyance response for sonic boom levels that range from unacceptable to imperceptible. There are a number of areas that need to be addressed to support the standards setting process, but one of the primary ones is metrics validation and sensitivity studies for a wide range of boom levels.

The research tasks are designed to support FAA and NASA activities on supersonics and sonic boom research. As the research progresses, this may involve the support of testing, data acquisition and analyses, of field demonstrations, laboratory experiments or theoretical studies.

Task 1 Study of Variability Effects

The Pennsylvania State University

Objective

The objective of this activity is to continue research at The Pennsylvania State University in the ASCENT COE to complement the sonic boom standards development ongoing within the Committee for Aviation Environmental Protection's (CAEP) Working Group 1 (Noise Technical), Supersonics Standards Task Group (SSTG). This research will ensure that the behavior of the sonic boom metrics considered in the SSTG discussions are well-understood prior to down-selecting a finalized metric or metrics for use in possible sonic boom certification and/or rulemaking.

Research Approach

Similar to the work in 2015, various sonic boom noise metrics have been calculated for a number of sonic booms, primarily N-wave signatures. The newly computed metrics dataset utilized high-quality recordings from the Superboom Caustic Analysis and Measurement Program (SCAMP) [Page, *et al.,* 2013] and Farfield Investigation of No-Boom Thresholds (FaINT) [Cliatt, *et al*., 2016] experiments conducted by NASA. With these signature datasets comprised of microphone measurements along substantial linear arrays, one can assess the waveform variability due to atmospheric turbulence influences across the arrays. Preferred boom events from these NASA datasets were then chosen after review of the flight conditions, flight objectives and actual waveforms generated in order to study only the non-focused, N-wave sonic boom signatures.

The sonic boom metrics chosen for application in the 2016 Project 7 studies are those described in a recent multi-author report describing a down-selection of appropriate sonic boom metrics [Loubeau, 2015], namely A-weighted sound exposure level, B-weighted sound exposure level, E-weighted sound exposure level, Steven's Mark VII perceived loudness, and NASA's Indoor Sonic Boom Annoyance Predictor. These metrics are abbreviated SEL_A, SEL_B, SEL_E, PL, and ISBAP.

Metrics robustness investigation

A major effort in Task 1 in 2016 was to investigate the robustness of sonic boom metrics to atmospheric absorption effects. It is well understood that the lowest altitudes of the atmosphere contain the planetary boundary layer, and that propagating through the atmospheric turbulence in that boundary layer distorts sonic boom signatures. N-wave sonic booms are prone to both spiking and rounding at both the front and back shocks comprising the signature, and the effect seems random. In the WG1 and SSTG discussions regarding picking an appropriate metric for use in certification, the question arose as to which of the metrics mentioned previously are the most robust with respect to turbulent distortion effects. That is, which metric is the least sensitive to turbulence effects.

After appropriate non-focused sonic boom signatures from the SCAMP dataset were identified, an effort was made to employ the Locey/Sparrow finite impulse response filters [Locey and Sparrow, 2007] to add turbulence to the measured data. Hence a number of turbulized sonic boom realizations were created from the clean signatures, and the above metrics were employed to see which metric had the smallest change in dB value caused by the effects of turbulence.

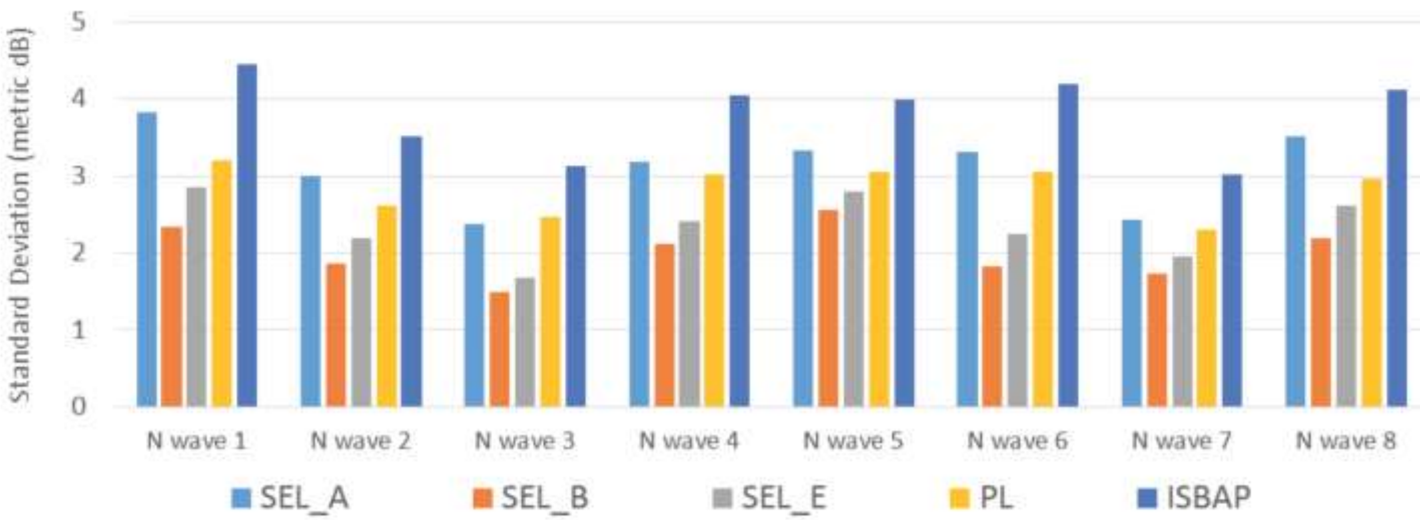

Figure 7.1. Influence of atmospheric turbulence on 8 N-wave sonic boom signatures for 5 different sonic boom metrics. Each bar shows the standard deviation in that metric in dB due to the turbulence effects. SEL_B shows the lowest SD (best, most robust) due to the turbulence effects. SEL_E is next best.

In Figure 7.1 it can be seen that for the 8 N-wave sonic booms selected, and the 10 turbulence filters available for producing the turbulence effects, that the SEL_B metric was the most robust (least sensitive), showing the smallest standard deviation in metric value. SEL_E showed the 2nd most robust characteristics. Not shown here, but an additional set of sonic boom waveforms, corresponding to low-boom signatures of an ASCENT industrial partner, were also carefully examined. In short, the industrial partner's low-boom sonic boom signatures were similarly affected by the atmospheric turbulence filters. For the low-boom signatures, SEL_B values were least affected by the simulated turbulence. The Penn State team is currently working on preparing a manuscript for submission to an archival journal to fully report these results.

Deturbing investigation

In 2016 the Penn State team also spent substantial time thinking about how to remove turbulence from ground-measured sonic boom signatures, a process referred to by some as "de-turbing". This is a lofty goal, and one that would be invaluable to the supersonics certification community.

The approach that Penn State took in 2016 focused on cross-correlation and averaging across a linear array of microphone measurements to remove the fine scale turbulence. This did work for the fine scales, but it did not work for the large scale turbulence which still required having the front shock and rear shocks be symmetric. That is OK for N-wave sonic booms, but this latter de-turbing method will not work for low-boom waveforms. Hence, additional work or alternative methods will be required. It was established, however, that for any de-turbing procedure that an estimation (or direct knowledge) of a clean sonic boom signature without turbulence is required. Essentially, you need to know your clean sonic boom waveform in advance in order to remove the turbulence from ground measured microphone data.

Some in WG1 and SSTG have suggested that the simplest thing one can do to measure clean sonic boom signatures is to suspend the microphone measuring equipment above the turbulence using balloons, sailplanes, motor gliders, or unmanned aerial vehicles. Such setups would be quite elaborate compared to today's typical practice of placing microphones on ground boards, so it seems that having a working de-turbing procedure would be very welcome.

Milestone(s)

N/A

Major Accomplishments

Project 7, task 1 showed that some sonic boom metrics are less sensitive to atmospheric turbulence than others. It was determined that B-weighted sound exposure level was the most robust metric out of several candidate metrics.

Publications

J. Palmer and V. Sparrow, "Measured N-wave sonic boom events and sensitivity in sonic boom metrics," in *Recent Developments in Nonlinear Acoustics*, AIP Conf. Proc. **1685** 090012 (AIP, 2015), doi: 10.1063/1.4934478. (This conference publication describes the work performed in 2015 on Project 7 Task 1.)

Outreach Efforts

None.

Awards

V. Sparrow gave the 2016 Rayleigh Lecture to the American Society of Mechanical Engineers (ASME) Noise Control and Acoustics Division on November 15, 2016 at the 2016 International Mechanical Engineering Congress and Exposition in Phoenix, AZ. The title of the talk was "Two approaches to reduce the noise impact of overland civilian supersonic flight."

Student Involvement

William Doebler is the graduate research assistant funded by the Applied Research Laboratory on Project 7. He is currently working toward his Ph.D. at the Penn State Graduate Program in Acoustics.

Plans for Next Period

Project 7 Task 1 ended in July 2016. The work to support CAEP WG1 and SSTG will continue in ASCENT Project 41.

References

L. Cliatt, *et al*., "Lateral cutoff analysis and results from NASA's farfield investigation of no-boom thresholds," NASA TM-2016-218850 (2016).

L. Locey and V. Sparrow, "Modeling atmospheric turbulence as a filter for sonic boom propagation," Noise Control Eng. J. **55**(6) 495-503 (2007).

A. Loubeau, *et al*., "A new evaluation of noise metrics for sonic booms using existing data," in *Recent Developments in Nonlinear Acoustics*, AIP Conf. Proc. **1685** 090015 (AIP, 2015).

D. Maglieri, *et al.*, *Sonic Boom: Six Decades of Research* (NASA SP-2014-622, 2014), pp. 51-52.
J. Palmer and V. Sparrow, "Measured N-wave sonic boom events and sensitivity in sonic boom metrics," in *Recent Developments in Nonlinear Acoustics*, AIP Conf. Proc. **1685** 090012 (AIP, 2015), doi: 10.1063/1.4934478.
J. Page, C. Hobbs, E. Haering, D. Maglieri, R. Shupe, C. Hunting, J. Giannakis, S. Wiley, F. Houtas, "SCAMP: Focused sonic boom experiment execution and measurement data acquisition," AIAA paper 2013-0933, 51st AIAA Aerospace Sciences Meeting, Grapevine, TX, January 2013.

Task 2 Community Instrumentation and Monitoring

The Pennsylvania State University

Objective

The research is being conducted in anticipation of future low boom community field tests. The community instrumentation and monitoring task was undertaken to facilitate a pro-active approach to interacting with communities participating in future field tests.

Research Approach

The research includes the assessment of community noise impact and methods to assess public acceptability of low boom signatures. Aspects of this research include identifying cost effective methods to measure noise and to observe community response to noise impact by monitoring social media dynamics in the community during the field test.

Milestone(s)

Research was conducted in support of future NASA sponsored low boom community impact field tests which will support FAA in future certification and regulatory decisions. The development of cost effective noise monitors to augment existing field monitors was initiated, in an effort to optimize measurement requirements and minimize costs in future field tests. Social media monitoring tools were investigated, as a means to observe social dynamics and to provide insights into community perceptions of noise impact during the field tests.

Major Accomplishments

Social Media Monitoring Tools

The social media monitoring task is evaluating options that would allow researchers to observe the social dynamics in the overall community response during a low boom community field test. The intent is to observe community perspective on noise impact. By monitoring on line discussions we have the opportunity to identify concerns within the community related to the proposed or ongoing low boom community field test. The research team could then engage the community with targeted Outreach materials that address issues observed on posts to social media.

Social media monitoring tools are a soft sensor to observe community dynamics on population-centric media such as Facebook or Twitter. The use of a geographic based topic specific search of social media can be used to observe community dynamics. The search is dependent on users with the location feature enabled on the device that they are using to post. An article on PewInternet.org indicated that among adult social media users ages 18 and older, 30% say that at least one of their accounts is currently set up to include their location in their posts.[1] A fact sheet from the Pew Research Center provided the following chart on social media usage growth from 2005 to 2013 by age group.

[1] "Social Networking Fact Sheet." Pew Research Center Internet Science Tech RSS. N.p., 27 Dec. 2013. Web. 11 Mar. 2016. <http://www.pewinternet.org/fact-sheets/social-networking-fact-sheet/>.

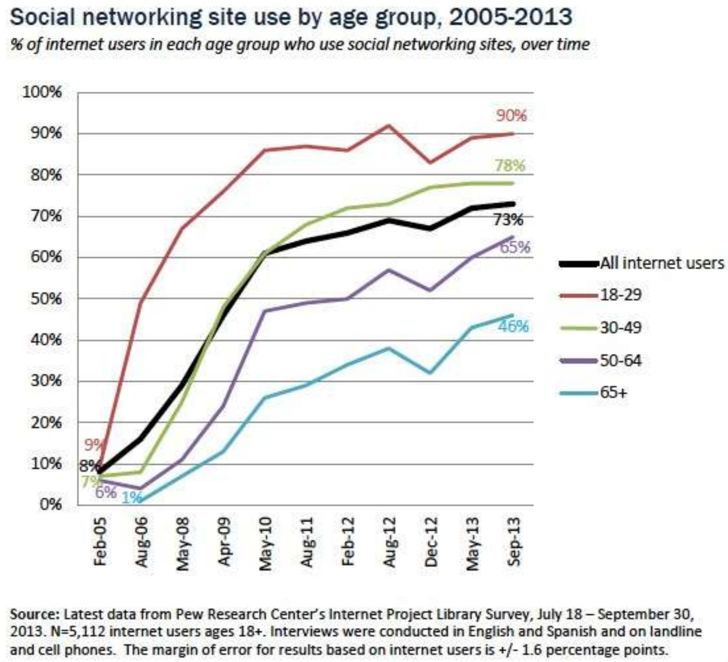

Figure 7.2. Social media site usage from 2005 -2013[2]

Figure 7.2 shows the growth of social media usage in the recent past, across all age groups. The use of social media monitoring affords the means to observe a community response to an event. The information will be used to draft news releases and outreach information. The social media observations are intended to inform the researchers of social climate and dynamics within community and are not considered to be subjective response test data.

We explored the use of the social media monitoring tool GeoFeedia, which excelled in visualization of the data analysis. However, the cost was $1000 per data set, which was too costly for this project, or for the real time support of the NASA field tests. We attempted to negotiate a reduced cost since it is for research purposes, but were not able to make that negotiation work. We are conducting tests of EchoSec, a social media monitoring tool that is $1068 per year, but has less archived data available, and different visualization of the data. The exploration of this tool's applicability in support of community response testing continues.

[2] "Social Networking Fact Sheet." Pew Research Center Internet Science Tech RSS. N.p., 27 Dec. 2013. Web. 11 Mar. 2016. <http://www.pewinternet.org/fact-sheets/social-networking-fact-sheet/>.

Figure 7.3. Snapshot of hits on boom comments using Echosec (https://www.echosec.net/)

The use of social media monitoring as a supplemental field research method affords a secondary means to observe a community response to an event, provided the biases and limitations of the approach are included with the observations.

Low Cost Noise Monitor (LCNM) Instrumentation

The team is designing a low cost noise monitor using commercial off the shelf (COTS) technology to measure low booms in support of future NASA low boom field tests. The purpose is to identify cost effective methods to measure noise in the community during the field test. The low cost noise monitor (LCNM) should be a self-powered weather proof rugged system. Several designs were considered, and component selection has been made and a prototype is in development. The LCNM design is mirroring, to the extent possible, the technical requirements that were used to develop the Sonic Boom Field Kits, or Sonic Boom Unattended Data Acquisition Systems (SBUDAS), briefly detailed below. The low cost noise monitors will be recording the same signals as the Field Kits. Some degradation in capabilities is expected in exchange for the reduction in cost. There is a desire to develop a lower cost monitor that can meet as many specifications as possible. The cost per unit should be on the order of $2K to $3K (if possible), maximum $5K, depending on the design and capabilities.

Signals:

- Outdoor sonic boom signatures (dynamic pressure)
- Time code for synchronization. GPS coordinates.
- Weather rugged recording mechanism

Existing High Fidelity Field Kit (SBUDAS) Sensors / Recording:

- Local Channel Count: 4 to 8 channels of A/D depending on the application
- Frequency range:
  - 1 Hz to 20 kHz (ICP mics). DC to 20 KHz (externally polarized mics).
  - Qualitative measures of signatures require a response that is flat from 0.1Hz-10KHz.
- Maximum pressure:
  - carpet boom measurements: < 1 psf (125 dB re 20 mPa)
  - focus boom measurements: < 10 psf (145 dB re 20 mPa)
- Dynamic Range: >104 dB / 24 bit
- Mic Noise Floor: <20 dBA due to mic (could be higher in focus boom config. due to NI dynamic range)

Several low cost options have been explored. A basic system is being investigated, with a single board computer, microphone, and batteries. Methods to acquire data for the entire duration of the test on remotely deployed systems are being investigated. The units are being design with a GPS receiver, similar to the one use in the SBUDAS field kits. The design is dependent on the addition cellular connectivity for remote triggering. Several designs were investigated considering the electrical power considerations, mechanical components, and the electrical data flow and data storage. The design includes two microphone channels that can be set with different dynamic ranges. This affords the ability to capture low level signals with integrity, and affords a second microphone channel set with a higher dynamic range in case there is a focus boom. The overall design that was selected for implementation is reflected in the following schematic.

Low Cost Noise Monitor Chosen Design

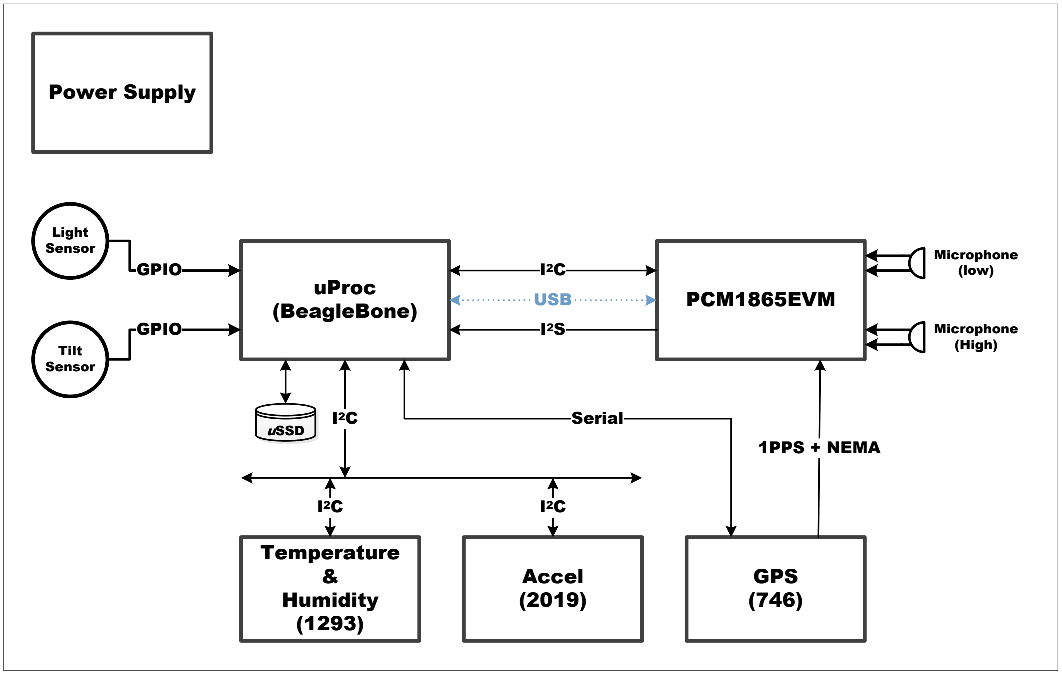

Figure 7.4.

The design includes an accelerometer channel, to allow the LCNM to have greater applicability for a wider range of noise monitoring projects, in addition to the support of the upcoming low boom field tests. Design selection was contingent on the availability of low cost parts for the monitor. Parts have been ordered and a proto-type will be developed and tested in a follow on effort. Field implementation of the LCNM requires development of software to facilitate the ability to readily download the field data.

Publications
None

Outreach Efforts
This research task supports NASA activities on supersonics and sonic boom research. The team has provided information to the NASA sponsored Waveforms Sonicboom Perception and Response Risk Reduction (WSPRRR) team. This NASA sponsored team consists of ASCENT Project 7 team members from Penn State, Volpe, Wyle and Gulfstream working with NASA team lead APS to formulate a test plan for future low boom community field tests.

Awards
None

Student Involvement
Mitch Gold is a PSU IST student working on the Social Medial Monitoring task. He is supported through the Federal Cyber Corps Scholarship for Service (SFS) program, which is offered and funded through the National Science Foundation (NSF) and the Department of Homeland Security (DHS). The PSU SFS program is administered through the College of Information Science and Technology and the Applied Research Lab. Because this appointment is funded externally, it does not count as cost share.

Plans for Next Period

The effort to expand the ability to observe the response within a community to a low boom field test led to the decision to also evaluate additional instrumentation and methods to document the noise impact across the community.

- The Research Instrumentation task will continue to assess the fidelity of lower cost noise monitors to optimize noise measurement requirements and minimize costs in future field tests.
- The Monitoring task will further evaluate social media as a means to observe social dynamics in the community that provide insights that afford the opportunity for subsequent Outreach.

References

"Social Networking Fact Sheet." Pew Research Center Internet Science Tech RSS. N.p., 27 Dec. 2013. Web. 11 Mar. 2016. <http://www.pewinternet.org/fact-sheets/social-networking-fact-sheet/>.