FINAL REPORT

Project 7
Civil, supersonic over-flight, sonic boom (noise) standards development, Study of variability effects (Task #1)

The Pennsylvania State University

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- FAA Award No.:13-C-AJFE-PSU Amendment 003, 013
- Period of Performance: August 4, 2014 to July 31, 2016
- Task(s):
    1. Study of Variability Effects

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. Task 1 FAA funding to Penn State in 2014-2016 totaled $90,000.

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)
ARL Graduate Research Assistant Will Doebler (Task 1: variability effects investigation)

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 ASEL, BSEL, ESEL, 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.

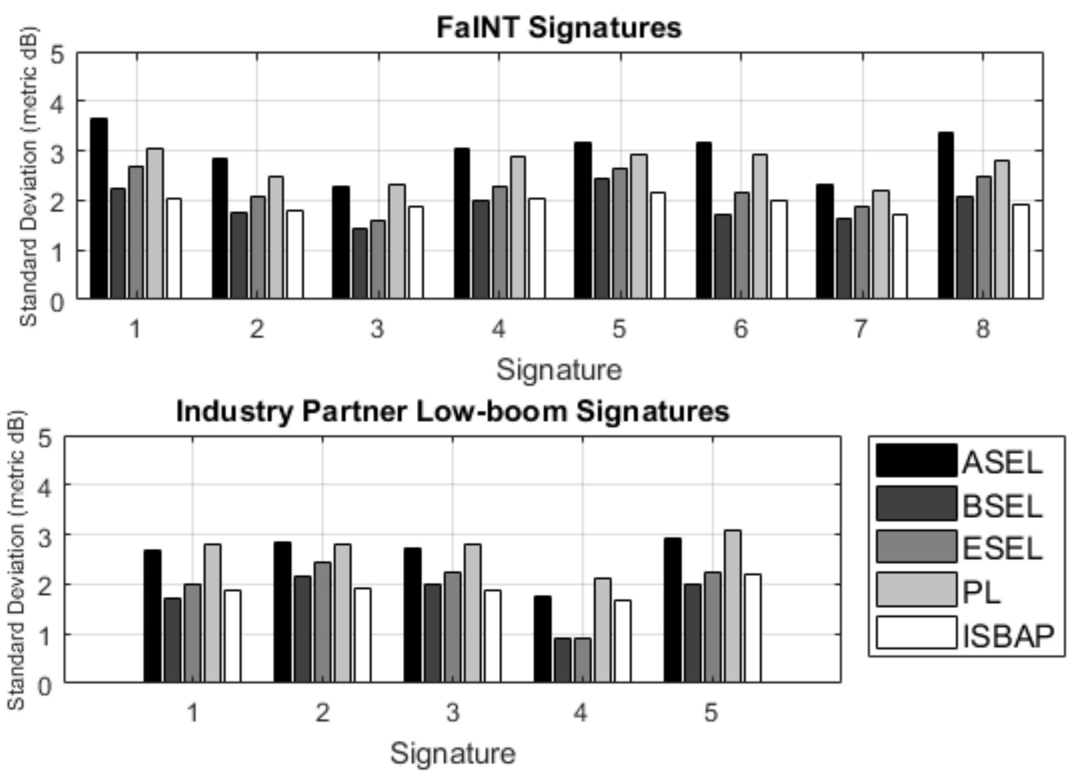

Figure 1. Influence of atmospheric turbulence on 8 N-wave sonic boom signatures [Top] and on 5 industry partner low-boom signatures [Bottom] for 5 different sonic boom metrics. Each bar shows the standard deviation in that metric in dB due to the turbulence effects. BSEL and ISBAP generally show the lowest SD (best, most robust) due to the turbulence effects. SEL_E is next best.

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.

In the top row of Figure 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 BSEL and ISBAP metrics were the most robust (least sensitive), showing the smallest standard deviation in metric value. ESEL showed the next most robust characteristics. The same trends are seen in the bottom row of Fig. 1 for an additional set of sonic boom waveforms, corresponding to low-boom signatures of an ASCENT industrial partner. One can see that the industrial partner's low-boom sonic boom signatures were similarly affected by the atmospheric turbulence filters. The Penn State team is currently publishing these results in the Journal of the Acoustical Society of America to fully report these findings [Doebler and Sparrow, 2017 and 2018].

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 sufficient 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 (BSEL) and the Indoor Sonic Boom Annoyance Predictor (ISBAP) were the most robust metrics 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 publication describes the research performed in 2015 on Project 7 Task 1.)

W. J. Doebler and V. Sparrow, "Stability of sonic boom metrics regarding signature distortions from atmospheric turbulence," JASA Express Letters, J. Acoust. Soc. Am. **141** (6) EL592-EL597 (June 2017). See also next reference.

W. J. Doebler and V. Sparrow, "Erratum: Stability of sonic boom metrics regarding signature distortions from atmospheric turbulence," [J. Acoust. Soc. Am. **141** (6) EL592-EL597 (2017)]," J. Acoust. Soc. Am. **144**, in press, (2018).

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).
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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.