Project 041 Identification of Noise Acceptance Onset for Noise Certification Standards of Supersonic Airplanes

The Pennsylvania State University

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- Period of Performance: August 7, 2017 to December 31, 2018
- Task(s):
  1. Obtaining confidence in signatures, assessing metrics sensitivity, and adjusting for reference day conditions

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- FAA Award No.: 13-C-AJFE-PSU Amendments 35 and 39
- Period of Performance: August 7, 2017 to July 31, 2019
- Task(s):
  2. Community Instrumentation and Monitoring

Project Funding Level

This project supports the identification of noise acceptance onset for noise certification standards of supersonic airplanes through research conducted on multiple tasks at the Penn State University. The FAA funding to Penn State in 2017 -2018 was $221K comprised of $150K to Task 1 and $71K to Task 2. Matching funds are expected to meet cost share on both Tasks. Funds have not been received to support these tasks during 2018-2019 at the time of the writing of this report.

Investigation Team

For 2017-2018 the investigation team includes:

The Pennsylvania State University
Victor W. Sparrow (Co-PI) (Task 1)
Kathleen K. Hodgdon (Co-PI) (Task 2)
Researcher: John Morgan R&D Engineer (Task 2)
College of Engineering Graduate Research Assistants Janet Xu and Luke Wade (Task 1: Signatures and metrics investigation)
ARL Eric Walker Graduate Assistant: Annelise Hagedorn (Task 2: Community Monitoring)

Project Overview

FAA participation continues in International Civil Aviation Organization, Committee on Aviation Environmental Protection (ICAO CAEP) efforts to formulate a new civil, supersonic aircraft sonic boom (noise) certification standard. This research investigates elements related to the potential approval of supersonic flight over land for low boom aircraft. The efforts include investigating certification standards, assessment of community noise impact and methods to assess public acceptability of low boom signatures. The proposed research will support NASA in the collaborative planning and execution of human response studies that gather the data to correlate human annoyance with low level sonic boom noise. 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- Obtaining Confidence in Signatures, Assessing Metrics Sensitivity, and Adjusting for Reference Day Conditions

The Pennsylvania State University

Objective

As national aviation authorities move forward to develop noise certification standards for low-boom supersonic airplanes, several research gaps exist in the areas of signature fidelity, metrics, metrics sensitivity to real-world atmospheric effects, adjustments for reference-conditions, etc. Research support is needed by FAA and international partners in these areas to progress toward standards.

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, and account for sonic boom variability effects, to move forward with sonic boom noise certification standards development and consideration of subsequent rulemaking.

Task 1 in ASCENT Project 41 focuses on several, but not all, research initiatives needed to move forward toward the development of a low-boom supersonic en-route noise certification standard. In addition, this project supports the travel of V. Sparrow so that he can serve as co-rapporteur of the CAEP Impacts and Science Group (ISG).

Research Approach

Background

Previous work in the last few years of ASCENT Project 41 has focused on a number of different topics associated with developing approaches that could lead to the sonic boom noise certification of future supersonic aircraft. For example, the work described in the Project 41 annual report last year focused on the appropriate placement and number of microphones that could be used during certification. It was found that at least 10 microphones are required to minimize the confidence intervals. The authors are currently writing up those results for submission to a peer-reviewed journal.

One of the ongoing topics of discussion is to determine how one can remove the effects of atmospheric turbulence from sonic boom signatures (pressure versus time recordings). The term currently used for removing the turbulence is called deturbing and this concept had previously been discussed in Project 41. Since there has never been a thorough investigation on methods for deturbing, this was the focus of the Project 41 Task 1 effort in 2017-2018. The work was primarily undertaken by Graduate Research Assistant Janet Xu, supplemented by project PI Dr. Victor Sparrow and Graduate Research Assistant Luke Wade. The detailed description has been prepared for submission to a peer-reviewed journal, and the following paragraphs provide an overview of some of the research development and initial results.

Categories of deturbing methods
Developed methods include those performed on individual sonic boom signatures to output the same number of deturbed signatures (individual deturbing), those performed on an ensemble of signatures to output one deturbed signature (group deturbing), and those based on matching the sonic boom signature to a database of known signatures (comparative deturbing). Work has primarily been carried out on the first two methods.

Individual deturbing methods
The two individual methods tested were low-pass filtering and turbulence subtraction. Low-pass filtering involves filtering around the shocks of the signature in order to retain the high-frequency shock features while removing turbulent noise. Turbulence subtraction is based on the fact that the back shock of an ideal N-wave behaves like a step function. Any difference from this idealized step function is subtracted off, giving an estimate for the turbulence present during the back shock. This estimated turbulence is then removed from the front and back shocks to give a deturbed waveform. Note that this method is only effective for N-wave-like signatures.

Group deturbing methods
Nearly every type of group deturbing ends with the ensemble of signatures being averaged. However, turbulence can cause each recorded signature to have a different shock width so that the signatures become misaligned. Thus, the key difference between each of the group deturbing methods is how they re-align the ensemble of signatures before they are averaged. One may choose not to align before averaging, or to individually deturb the signatures and average without aligning, but different methods of alignment were also explored. These include aligning by peak, aligning by maximum slope, and aligning by maximum cross-correlation. Aligning by peak determines the width of each signature by finding the time difference between the peak of the front shock and the peak of the back shock, then resampling ("time-stretching") the signature so that its width matches the width of the median width signature (i.e., their peaks align). Aligning by maximum slope determines the width by finding the time difference between the point of maximum slope in the front shock and the point of maximum slope in the back shock, then time-stretching the signature so that its width matches the width of the median width signature (i.e., their points of maximum slope align). Aligning by maximum cross-correlation does not assume features of the shocks. Rather, it aligns each signature to a reference signature by scaling and shifting the signature until maximum cross-correlation with the reference signature is achieved. All the signatures are then time-stretched to have the same width as the median width signature, where width is determined by maximum slopes as outlined above. A method known as dynamic time warping was also investigated. It involves pairing off and nonlinearly mapping signatures onto each other tournament-style until one composite signature remains.

Initial comparisons of the deturbing methods
The effectiveness of each deturbing method was determined by the closeness of the output deturbed signature to the original input signature, using both an objective metric (energy normalized mean-square error) and several subjective metrics (Stevens Mark VII Perceived Level, ISBAP, ASEL, and BSEL). Table 1 contains the mean square error for each deturbing method for different sonic boom datasets. Note that each dataset has two rows per deturbing method. This corresponds to using two separate methods to calculate points of maximum slope for a signature where applicable. The heatmap highlights the largest (red) and smallest (white) MSE for each set of two rows, and shades of red for the in-between values. It can be seen that averaging with time-stretching by maximum slope and low-pass filtering with averaging (LPF (group)) were the most effective in achieving a low MSE match. The former implies that the location of maximum slope in the pressure signature may be the feature most robust to noise, while the latter implies that low-pass filtering may improve the alignment of the average without the need for time-stretching.

Table 1. Normalized mean square error for each deturbing method for various sonic boom datasets. The heatmap displays where the PL is lower than in the original signature (blue) and higher (red)

		Individual		Group						
Data Set	None	LPF	Sub	None	Peak	Slope	Xcorr	DTW	LPF	Sub
Stout/SonicBAT	5.119	4.209	1.975	0.907	2.329	0.930	1.689	25.974	0.757	0.993
	x	x	1.829	0.925	x	0.924	1.689	24.554	0.788	0.996
Northrup	3.989	3.407	2.127	2.605	2.766	1.461	1.581	20.533	2.543	1.620
	x	x	2.074	2.474	x	1.400	1.581	20.314	2.503	1.616
SSBD	1.853	1.687	2.631	1.319	1.596	1.297	1.310	15.070	1.299	2.379
	x	x	3.139	1.340	x	1.420	1.301	16.785	1.288	2.724
L.Boom 1	2.379	2.198	2.813	0.429	0.388	0.301	0.626	15.171	0.412	0.920
	x	x	2.577	0.374	x	0.315	0.625	14.444	0.358	0.758
L.Boom 2	3.206	3.046	3.745	3.899	0.634	1.658	1.271	10.014	2.631	5.377
	x	x	3.715	0.452	x	0.436	1.273	7.947	0.466	4.815
L.Boom 3	2.119	1.924	2.901	1.148	1.097	0.266	0.896	12.485	0.534	1.448
	x	x	3.228	0.870	x	0.274	0.894	15.664	0.863	1.152
L.Boom 4	1.220	1.111	4.654	0.189	0.214	0.604	0.439	5.093	0.179	3.235
	x	x	4.821	0.187	x	0.573	0.440	4.145	0.177	3.343
L.Boom 5	1.026	0.967	11.682	0.131	0.339	0.139	0.322	16.101	0.123	10.819
	x	x	8.786	0.152	x	1.548	0.322	35.613	0.141	6.857

Table 2 contains the change in Stevens Mark VII Perceived Level (PL) for each deturbing method for different simulated sonic boom datasets. Note that each dataset has two rows per deturbing method. This corresponds to using two separate methods to calculate points of maximum slope for a signature where applicable. The heatmap displays where the PL is lower than in the original signature (blue) and higher (red). It can be seen that the smallest changes in PL occur for individual low-pass filtering (LPF), dynamic time warping (DTW), and averaging with time stretching by maximum slope (Slope). The DTW result may be misleading, however, as it has such a high MSE across the board (see Table 41.1).

Table 2. PL change for each deturbing method for various sonic boom datasets. Same heatmap as in Table 1.

			Individual		Group						
Data Set	Source	None	LPF	Sub	None	Peak	Slope	Xcorr	DTW	LPF	Sub
Stout/SonicBAT	99.4	-1.7	-2.1	1.4	-3.0	-5.4	-2.9	-4.0	-5.1	-3.6	-1.6
	x	x	x	2.2	-2.1	x	-2.3	-4.0	-5.5	-2.7	0.8
L.Boom 1	77.7	-1.8	-0.1	11.6	-4.9	-5.0	-2.8	-5.6	2.3	-4.0	7.4
	x	x	x	11.2	-4.4	x	-3.1	-5.6	2.2	-3.2	6.6
L.Boom 2	80.0	-2.1	-2.0	1.9	-5.9	-4.1	-5.9	-5.4	1.4	-5.4	-3.6
	x	x	x	2.7	-3.4	x	-3.2	-5.4	-0.8	-3.9	-3.4
L.Boom 3	74.2	-2.3	0.8	7.7	-7.5	-5.7	-2.7	-6.4	-1.0	-4.6	2.2
	x	x	x	8.3	-6.4	x	-3.7	-6.3	-1.3	-4.6	3.9
L.Boom 4	69.0	-1.6	-1.1	23.9	-6.6	-3.7	-1.8	-4.8	5.9	-6.7	20.8
	x	x	x	24.4	-6.2	x	-1.6	-4.8	6.4	-6.2	21.0
L.Boom 5	69.3	-2.0	1.4	18.8	-4.7	-6.8	-2.4	-7.0	0.4	-3.1	15.2
	x	x	x	17.4	-3.4	x	-3.3	-7.0	3.8	-2.0	14.3

As a result, it is suggested that individual low pass filtering, averaging with time stretching by maximum slope, low pass filtering before averaging, and averaging with time-stretching by cross correlation be used for deturbing if applied in sonic boom aircraft certification.

Milestone(s)
A number of different methods were assessed for removing the effects of atmospheric turbulence on recorded sonic boom signatures.

Major Accomplishments
ASCENT Project 41 Task 1 has now provided guidance to remove atmospheric turbulence from sonic boom signatures that could be used in sonic boom noise certification of supersonic aircraft.

Publications
J. Xu, V. Sparrow, "Investigation of deturbing methods for sonic boom signatures," J. Acoust. Soc. Am. **143**(3, Pt. 2) 1913 (2018), 7-11 May 2018 Acoustical Society of America presentation, Minneapolis, MN, USA.

Outreach Efforts
None

Awards
None

Student Involvement
Janet Xu was the Penn State graduate research assistant who worked on ASCENT Project 41 during the 2017-2018 academic year. She now has taken a job at Bose Corporation where she continues to work on the topics of acoustics and signal processing. Luke Wade also came on the project during the summer of 2018 and overlapped with Janet Xu for a few weeks.

Plans for Next Period
If funding arrives, the plan is to continue supporting CAEP's WG1, SSTG, and ISG in the area of supersonic certification.

References
[1]J. Xu, V. Sparrow, "Investigation of deturbing methods for sonic boom signatures," J. Acoust. Soc. Am. **143**(3, Pt. 2) 1913 (2018), 7-11 May 2018 Acoustical Society of America presentation, Minneapolis, MN, USA.
[2]D. Maglieri, *et al.*, *Sonic Boom: Six Decades of Research* (NASA SP-2014-622, 2014), pp. 51-52.

[3]M. Muller, Dynamic Time Warping, (Springer Berlin Heidelberg, Berlin, Heidelberg, 2007), doi: 10.1007/978-3-540-74048-3_4.

Task 2- Community Instrumentation and Monitoring

The Pennsylvania State University

Objective

This is part of a series of research efforts that were designed to devise scientific evidence to help answer the question: "What data is needed through a standard to reconsider 14 CFR part 91.817, which currently prohibits civil supersonic flight over land?" This effort supports research on the human perception of *low level* sonic booms and the exploration to enhance capabilities for the assessment of community impact by aviation noise field tests.

The research supports the standard development process and the identification of noise acceptance onset. The tasks were conducted in support of NASA in the development of protocols, methods and planning for execution of human response studies and community exposure testing.

Research Approach

This research encompassed several topics that were investigated in support of future field tests to assess community noise impact and public acceptability of low boom signatures. Community noise impact research requires gathering noise data as well as community response data. This effort is finalizing the design of low cost noise monitors (LCNM) that could be used as a rapid deploy monitor to augment the use of standard higher fidelity instrumentation to gather noise data. A review of the aviation noise literature is underway. The intent is to assess differences in perception between urban and rural environments to better understand the potential impact that background environmental noise has on community noise impact.

Milestone(s)

This research was conducted in support of future NASA sponsored low boom noise community field tests. The LCNM design is being finalized. PSU researchers are sharing the design with researchers from Volpe, The National Transportation Systems Center for further testing and development. The literature review of urban vs. rural aviation noise impact is ongoing to assess the role of environmental background noise.

Major Accomplishments

The Low Cost Noise Monitor design is being finalized. This task was conducted in support of efforts to gather objective measurements community noise tests. The literature review of the impact of environmental background noise on community noise impact is ongoing. The review of environmental masking was initiated to understand the potential impact that masking has on noise field test results for human impact. Accomplishments on each of these tasks follow.

Low Cost Noise Monitor (LCNM) Design

A report that provides an overview of the design for the Low Cost Noise Monitors (See Figure 1 and Table 1) is in development. The design will be shared with Volpe for further development and testing. The LCNM was designed as a prototype with the potential for project specific modifications when building future monitors.

Figure 1. LCNM prototype

Table 1. LCNM Components

LCNM Components
2 Microphones
GPS Sensor
Environmental Sensor
Accelerometer Sensor
Single Board Computer (SBC)

Several low cost options were explored, assessing the electrical power considerations, mechanical components, and the electrical data flow and data storage. Design selection was contingent on the availability of low cost parts for the monitor. The noise monitoring is provided through a single board computer, microphones, and batteries. 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. The monitor also includes temperature and humidity sensors as well as an accelerometer channel to provide greater applicability for a range of noise monitoring projects. The monitor will require the development of software to facilitate the ability to readily download the field data.

Environmental Masking (urban vs suburban/rural) Literature Review and Survey Development
This task includes a review of concepts and available literature of noise studies related to the role masking plays on the perception of noise. Masking is the extent that one noise source “covers” or masks another noise source. The low boom noise has been described as sounding like distant thunder, or two car door slams in quick succession. In urban areas, a car door slam may not be noticed, due to other noise sources. The same car door slam would be more clearly noticed in a quiet rural environment. The noise impact is measured by both objective noise metrics and subjective human response.

The task will initially review and compile information on urban vs. rural impact of aviation noise. While the preferred noise source to investigate is aviation noise, data gathered on analysis methods for other noise sources may also prove to be relevant. A review of noise impact and analysis methods for various noise sources and environments could further identify patterns in noise impact and response, and provide a more informed approach to illuminate those patterns in future data sets. An attempt is being made to include a range of publications such as The Journal of the Acoustical Society of America, Journal of Sound and Vibration, Journal of Environmental Psychology, and Environment and Behavior. The literature review is intended to further understanding of potential differences in noise impact between such communities that could inform future research efforts. The results of this study should provide insight into the influence of background noise on the annoyance rating of aviation noise pertaining to low sonic boom noise.

Publications
None

Outreach Efforts
This research task supports NASA activities on supersonics and low boom research. The team has provided information to the NASA sponsored Waveforms Sonicboom Perception and Response Risk Reduction (WSPRRR) team as warranted.

Awards
None

Student Involvement
Annelise Hagedorn started this effort as an Eric Walker Graduate student, looking at aviation environmental impacts on urban vs rural communities. She left the university this past year for an excellent job opportunity.

Plans for Next Period
The LCNM instrumentation task is being finalized. The outcome is the development of noise monitoring technology that can be used to supplement existing noise measurement methods for greater quantification of coverage at lower cost and complexity. Such technology could be used as intermediate measures among the standard higher fidelity instrumentation to confirm and interpolate data.

The literature review will be continued on noise studies related to the role masking plays on the potential low boom noise impact in differing background noise for urban, suburban or rural noise environments. The findings of the Environmental Masking literature review will facilitate interpreting noise field test results and masking due to environmental surrounding (community density), and the relevance masking has on low boom noise for such varying background environments.

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