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

The Pennsylvania State University

University Members

Penn State Acoustics Program	Team Lead	Victor W. Sparrow
Penn State Applied Research Laboratory	Co-Principal Investigator	Kathleen K. Hodgdon

Advisory Committee Members

AERION: Jason Matisheck, Peter Sturdza, *et al.*
Boeing: Hao Shen, Bob Welge, *et al.*
Cessna: Kelly Laflin, *et al.*
Gulfstream: Robbie Cowart, Matthew Colmar, Brian Cook, Joe Gavin, *et al.*
Lockheed Martin: John Morgenstern, Tony Pilon*, et al.*
Volpe-The National Transportation Systems Center: Juliet Page, Bob Samiljan, et.al.
Wyle: Kevin Bradley, Chris Hobbs, *et al.*

Project Lead Investigator

Victor W. Sparrow
Director and Professor of Acoustics
Graduate Program in Acoustics
Penn State
201 Applied Science Bldg.
University Park, PA 16802
+1 (814) 865-6364
vws1@psu.edu

University Participants

The Pennsylvania State University

- P.I.: Vic Sparrow, Professor and Director, Graduate Program in Acoustics
- Researcher: Kathleen Hodgdon Research Associate
- FAA Award No.: 13-C-AJFE-PSU Amendment 21
- Period of Performance: June 28, 2016 to December 31, 2017
- Task(s):
  1. Obtaining confidence in signatures, assessing metrics sensitivity, and adjusting for reference day conditions

The Pennsylvania State University

- P.I.: Kathleen Hodgdon Research Associate
- Researcher: John Morgan R&D Engineer
- Researcher: Bernard Kozykowski
- FAA Award No.: 13-C-AJFE-PSU Amendment 25
- Period of Performance: July 21, 2016 to December 31, 2017
- Task(s):
  2. Community Impact and Acoustic Acceptability

Project Funding Level

This project supports the identification of noise acceptance onset for noise certification standards of supersonic through research conducted on multiple tasks at the Penn State University. FAA funding to Penn State in 2016-2017 was $160,000 comprised of $50K to Task 1 and $110K to Task 2. Matching funds are expected to meet cost share on both Tasks.

Investigation Team

For 2016-2017 the investigation team includes:

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: Signatures and metrics investigation)
ARL co-administered PSU Scholarship for Service undergraduate student Mitch Gold (Task 2: Community Monitoring)

Project Overview

FAA participation continues in 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 certification and/or 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. It addresses neither the important issues of acceptability of low-boom sonic boom nor appropriate metric levels that would eventually become part of a standard. The work proposed here supports CAEP/WG1 in the three areas of:

- obtaining confidence in acoustic signatures,
- assessing metrics sensitivity, and
- adjusting for reference day conditions.

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

Through the PARTNER and ASCENT Centers of Excellence programs, Penn State has been supporting CAEP/WG1 regarding the development of supersonic aircraft certification standards for 10 years. In recent years the focus has been on understanding the influence of atmospheric turbulence on low-boom waveforms. Work from 2013-2015 showed that both A-weighted sound exposure level and Steven's Mark VII Perceived Loudness (PLdB) metrics were substantially affected by atmospheric turbulence effects [Palmer and Sparrow, 2015]. One can actually hear the differences in the sonic boom waveforms heard 10s of meters away from each other. Thus, the turbulence effect will substantially complicate the data acquisition and signal processing for ground-based measurements to certify supersonic en-route flight. The procedures used to certify subsonic aircraft simply will not work for supersonic en-route noise.

Penn State also aided WG1/SSTG to develop a list of technical terms and definitions for sonic boom, as well as a metrics catalog to enumerate the wide variety of metrics that one could use for sonic boom noise. This development then was the basis for "down-selecting" a limited number of metrics to carry forward for possible use in a standard. [A. Loubeau, *et al.,* (2015)]

In the last year, Penn State's work in ASCENT Project 7 (Part A) has focused on two topics. The first has been to assess the sensitivity of the 5 "finalist" sonic boom metrics to atmospheric turbulence. As was reported to CAEP/WG1 in April 2016, the preliminary result is that B-weighted sound exposure level is the most robust with respect to turbulent distortions, both for N-wave shaped sonic booms and for industry supplied low-boom waveforms. Additional research will be necessary to understand why B-weighted SEL did the best, beating out both PLdB and NASA's Indoor Sonic Boom Annoyance Predictor (ISBAP). The second topic in Project 7, Task 1 has focused on developing signal processing approaches to remove turbulence from ground-measured signatures, described by some as "de-turbing." [Maglieri, *et al.,* 2014] The most recent Penn State work has indicated that to remove turbulent effects it is necessary to estimate a "clean" waveform using predictions or experimental measurements in the absence of turbulence.

Current work

There are several ongoing subtasks in ASCENT Project 41, Task 1. These include assessing the sensitivity of sonic boom metrics to turbulence, developing "de-turb" procedures, and considering the number and placement of ground-based microphones in a certification requirement. Previous work from Project 7 will also be extended to include an evaluation of the role of nonlinearity in obtaining confidence in supersonic signatures, as it relates to reference day-corrections. It is well known that the pressure signature (pressure versus time waveform) distorts substantially during propagation from aircraft to the ground, and one of the key influences on this distortion is acoustic nonlinearity, the fact that higher amplitude portions of the waveform propagate FASTER than lower amplitude portions of the waveform. [Pierce, 1981; Hamilton and Blackstock, 1998] Such acoustical nonlinearities and the resulting shock-induced inaccuracies will be addressed in the context of reference day-corrections. Recent results from other ASCENT projects, such as ASCENT Project 5 (Noise emission and propagation modeling), should be helpful with the task of relating the concepts of "reference day conditions" to future sonic boom certification procedures.

As in previous efforts the Penn State researchers will employ both analytical and computational approaches, supported by field data collected by NASA and others. Industry partners, such as Boeing, Cessna, Gulfstream Aerospace Corporation, Lockheed-Martin Aeronautics, Wyle, and others, will again be asked to provide guidance regarding the project and to provide important supersonic signature predictions that are both absolutely necessary to carry out the research and at the same time provide FAA-required cost sharing. Existing datasets such as those from recent NASA studies (SCAMP, FaINT, WSPR, etc) and NASA studies undertaken this year (SonicBAT and WSPRRR, as they come available) will be utilized.

In addition, work efforts include the support of NASA activities on supersonics and sonic boom research. This may involve the support of testing, data acquisition and analyses, of field demonstrations, laboratory experiments or theoretical studies.

Depropagation does not work for sonic booms

Early work in Project 41 Task 1 has shown that sonic boom propagation cannot be processed with the same de-propagation procedures that are commonly used for subsonic aircraft noise certification. Because of the physics of nonlinear acoustics and the presence of shocks in sonic boom waveforms, very different sonic booms signatures can all result in the same waveform on the ground. This makes the techniques of depropagation impossible for use with sonic booms. The Penn State team reported on this result during an SSTG procedures workshop in July 2016 at NASA Armstrong Flight Research Center, Edwards, CA. Subsequently the information was used in an SSTG and WG1 meeting in Cologne, Germany, and reported on in a CAEP Steering Group Meeting in Washington, DC in December 2016.

Appropriate placement and number of microphones for certification measurements

The Penn State team is making an effort to ascertain how to best make certification measurements in the primary sonic boom carpet. One would like to use as few microphones as possible and know how to locate them to maximum advantage. One possibility would be to minimize the metrics' 90% confidence interval for multiple measurements. Data from NASA's SCAMP program is now being evaluated to assess how removing selected microphones will change the narrowness of the confidence interval for different sonic boom metrics.

Milestone(s)

N/A

Major Accomplishments

It was established that one cannot apply depropagation techniques to sonic boom propagation.

Publications

None.

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 supported by the Applied Research Laboratory on Project 41 in 2016. He is pursuing his Ph.D. in the Penn State Graduate Program in Acoustics.

Plans for Next Period

Continue the work supporting CAEP WG1, SSTG, and ISG.

References

M. Hamilton and D. Blackstock, *Nonlinear Acoustics* (Academic Press, 1998).

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. 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.

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.

A. D. Pierce, *Acoustics* (McGraw Hill, 1981 & Acoustical Society, 1989), Chapter 11.

Task 2 Community Impact and Acoustic Acceptability

The Pennsylvania State University

Objective

This research addresses aspects of the FAA roadmap research question: “What is needed from a standard to reconsider 14 CFR part 91.817, which does not allow for civil supersonic flight over land?” The research supports the standard development process and the identification of noise acceptance onset. The tasks are proposed in support of NASA in the planning and execution of human response studies, and in the development of protocols, methods and planning for Community Exposure Testing.

Research Approach

The research includes the assessment of community noise impact and methods to assess public acceptability of low boom signatures. The effort will finalize research that was advanced under ASCENT Project 7 and begin new research. The ongoing efforts include the development and testing of low cost noise monitors (LCNM) and the evaluation of social media monitoring (SMM) methods as a means to observe general comments on noise within the field test community. A new task was initiated to conduct a review of differences in perception between urban and suburban/rural environments to better understand the potential impact that masking has on noise field test results for human impact.

Milestone(s)

This research was conducted in support of future NASA sponsored low boom noise community impact field tests. The development and testing of cost effective noise monitors to augment existing field monitors is ongoing. Social media monitoring tools are being investigated, as a means to observe social dynamics and to provide insights into community perceptions of noise impact during the field tests. A literature review was initiated for the background noise masking task. A review of social surveys was initiated and the environmental background noise survey will be considered for implementation during the first WSPRRR community test being conducted with a low boom flight maneuver, most likely in 2018, beyond this project reporting period.

Major Accomplishments

There are several ongoing subtasks in ASCENT Project 7 (Part B) that are being continued in Project 41 in 2016-2017. The continued tasks include finalizing an investigation of Low Cost Noise Monitors (LCNM) and identification of social media monitoring tools. These two tasks will support efforts to gather both objective measurements and subjective observations in test communities. A new task on environmental masking was initiated to understand the potential impact that masking has on noise field test results for human impact, and to develop an associated survey that can be used in future field tests. Accomplishments on each of these tasks follow.

Social Media Monitoring Tools

The monitoring of social media is being explored as a supplemental means to observe the impact of the noise field testing on the community, by observing the publicly available comments that are posted to social media. By monitoring online discussions, researchers have the opportunity to identify concerns within the community related to the proposed or ongoing low boom community field testing. A geographic based search of social media comments during a noise field tests may identify unexpected locations of potential sound channeling due to topography, urban canyons or environmental variability; or community concerns related to the field test. Being made aware of such issues, is valuable in helping to explain secondary influences on the primary data. The observations would be gathered from public domain information only and are not viewed as formal response data.

We are conducting tests of EchoSec, a social media monitoring tool. It appears that we may not have access to archived data from months ago, but we should be able to access "real time" events. We are identifying archived data from sonic booms or Space X booms and comparing findings from new articles to EchoSec searches. Figures 41.1 through 41.3 below compares information on a sonic boom that hit the east coast due to an F-35 that took place on January 28th, 2016. We are comparing content from established media outlets, in this case ABC News, with social media posts using Echosec.com.

Figure 41.1: Hammonton, NJ as the boom source (ABC News)   Figure 41.2: Impact of the Noise (ABC News)

"The boom was centered north of Hammontown, NJ, around 1:30 p.m. It was the first of nine booms reported in southern New Jersey and along the Eastern Seaboard to Long Island, New York in the hours following the initial boom, the USGS said." (http://abcnews.go.com/US/jersey-rocked-sonic-boom/story?id=36578433)

Based on the ABC News report we used a data selection of January 28, 2016 to January 29, 2016 to search EchoSec.

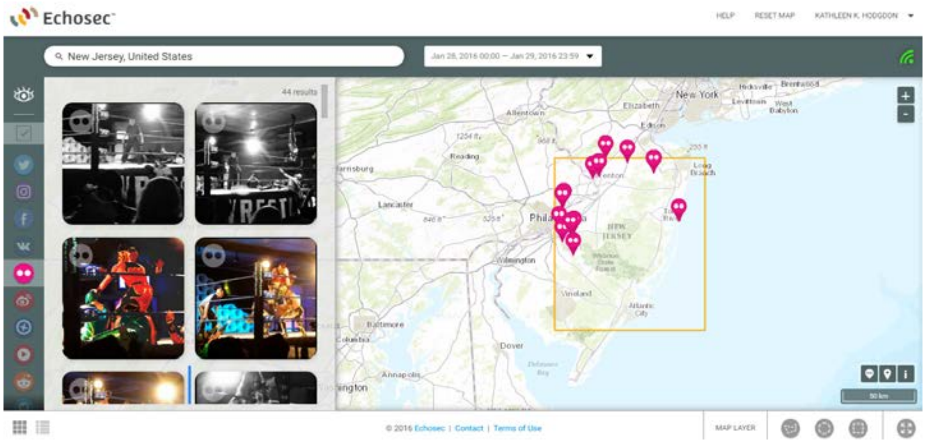

Figure 41.3: Echosec Social Media Search for Posts from Jan 28-29

As depicted in Figure 41.3, the social media application that is appearing is Flickr. As seen along the left side, all other social media sites are greyed out, indicating that the posts we are viewing were on Flickr. There were no available posts within both the selected dates and the geographic location that we specified for Twitter. We are assuming that Twitter will be a valuable social media site, and plan to focus future testing and analysis on Twitter more than Instagram, Reddit, Flickr, or other platforms. The project continues to explore applicability of EchoSec to this effort.

The observations would primarily allow the team to engage the community with targeted news releases or Outreach materials that address issues observed on posts to social media. The observations could also identify if community members have mistaken the impulsive boom noise to be an explosion, prompting the team to issue a media release to alleviate these concerns. While noise monitors will be located across the boom carpet, there is the potential that a combination of wind and terrain could produce a sound channel. The observations may indicate a "noise pocket" that could prompt locating a noise monitor in that area. Monitoring social media provides the opportunity to identify concerns within the community related to the low boom field test.

Low Cost Noise Monitor (LCNM) Instrumentation
The evaluation of LCNM is in progress assessing the applicability of commercial off the shelf (COTS) instrumentation for this effort. Design selection was contingent on the availability of low cost parts. The anticipated cost of components is reflected in the following table.

LCNM Component	Sensor	Cost
Microphones		
Quite Sounds: Rode NT1-A Cardioid Condenser Microphone Recording Package with a Tripod Base Microphone Floor Stand - Black	N/A	$236.00
Loud Sounds: Audio Technica AT2035 Large Diaphragm Condenser Microphone w/Shock Mount, Pop Filter, Mic Cable, and Mic Stand	N/A	$149.00
GPS Sensor		
Adafruit Ultimate GPS Breakout - 66 channel w/10 Hz updates - Version 3	MTK3339	$39.95

Environmental Sensor		
Adafruit BME280 I2C or SPI Temperature Humidity Pressure Sensor	BME280	$19.95
Accelerometer Sensor		
Adafruit Triple-Axis Accelerometer - ±2/4/8g @ 14-bit - MMA8451	MMA8451	$7.95
Single Board Computer		
ELEMENT14 BBONE-BLACK-IND-4G Beaglebone Black Industrial, Sitara ARM Cortex A8 Processor, 512 MB	N/A	$64.00
ELEMENT14 BBONE-GATEWAY-CAPE DEVELOPMENT BOARD, WIRELESS CONNECTIVITY	N/A	$55.00
Banana Pi M3 - BPI-M3 - Octacore A83T ARM Cortex-A7 2GB DDR RAM with WIFI Antenna	N/A	$73.00

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 design also includes an accelerometer channel, to allow the monitor to have greater applicability for a wider range of noise monitoring projects. The LCNM task will assess the fidelity of lower cost noise monitors to optimize noise measurement requirements and minimize costs in future field tests. PSU researchers are teaming with researchers from Volpe, The National Transportation Systems Center on this effort. 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 new task will conduct an initial review of concepts and available literature of 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. An undergraduate student will be hired to conduct a literature review and summary. A short list of potentially relevant articles follows.

Potential Reference Citations:

- Kuno, K., Omiya, M., Okumura, Y., Hayashi, A., Mishina, Y., & Oishi, Y. (2000). Criteria for environmental noise based on neutral reaction of inhabitants. Journal of the Acoustical Society of Japan, 21, 349-353.

- Weinstein, N. D. (). Individual differences in reactions to noise: A longitudinal study in a college dormitory. Journal of Applied Psychology, 63, 458-466.

- Sheikh, P. A., & Uhl, C. (2004). Airplane noise: A pervasive disturbance in Pennsylvania Parks, PA. Journal of Sound and Vibration, 274, 411-420.

- Vos, J. (1992). Annoyance Caused by Simultaneous Impulse, Road-Traffic, and Aircraft Sounds: A Quantitative Model. Journal of the Acoustical Society of America, 91, 3330-3345.

- Vos, J. (1998). The Loudness of Impulse and Road-Traffic Sounds in the Presence of Masking Background Noise. ACUSTICA, Vol. 84, 1119-1130

The literature review has just been started. The results of this study should 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.

The planning for an Urban vs. Rural Survey has been started with the PSU Survey Research Center. The survey will include questions identified for the NASA sponsored Waveforms Sonic boom Perception and Response Risk Reduction (WSPRRR) community field test, as well as some specific questions pertaining to the ease of hearing the boom in varying levels of background noise environments. This effort is being initiated now to allow time to develop the survey, to conduct a review of the survey instrument by both NASA and FAA, and to submit the design for regulatory approvals. The NASA WSPRRR community social survey will most likely be conducted in spring 2018, depending on the NASA field test schedule.

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 41 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.

ARL has afforded support of a Distinguished Undergraduate Research position to work on the literature review and background research or the Urban vs. Rural survey. This appointment begins in January 2017 with a cost share of approximately 46K per year. The student has not yet been selected.

Plans for Next Period

The SMM effort will finalize evaluations of social media monitoring tools as a means to observe social dynamics in the community. This evaluation of options would identify tools that allow us to observe the social dynamics in the overall community response during a low boom community field test.

The LCNM instrumentation task will finalize aspects related to ongoing 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. Additional software to facilitate the ability to readily download the field data could be developed in the next funding cycle.

The Environmental Masking literature review is applicable to low boom research and other environmental noise research. The development of the Urban vs. Rural Survey will result in a survey for use with the NASA WSPRRR community social survey will most likely be conducted in spring 2018. Additional funds would be required in the next annual funding cycle to implement this survey task in the field and to gather, analyze and correlate the response data with the noise measurements from the community field test.

References

Ruths, D., and J. Pfeffer. "Social Media for Large Studies of Behavior." *Science* 346.6213 (2014): 1063-064. 28 Nov. 2014. Web. 10 Feb. 2015.