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

The Pennsylvania State University

Project Lead Investigator

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University Participants

The Pennsylvania State University (Penn State)

- PI: Vic Sparrow, United Technologies Corporation Professor and Director, Graduate Program in Acoustics
- FAA Award Number: 13-C-AJFE-PSU Amendment Nos. 45 and 60
- Period of Performance: March 29, 2019 to February 28, 2021
- Tasks:
  1. Obtaining confidence in signatures, assessing metrics sensitivity, and adjusting for reference day conditions.
  2. Assessing secondary sonic boom propagation.

Queensborough Community College, City University of New York

- Co-Investigator: Kimberly A. Riegel, subrecipient to The Pennsylvania State University (Penn State

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 Penn State**.** The FAA funding to Penn State in 2019–2021 is $390,000. Matching funds are expected to meet cost share on both Tasks. Boom Supersonic has pledged $300,000 and Gulfstream has pledged $100,000.

Investigation Team

For 2019–2021, the investigation team includes:

- Victor W. Sparrow, PI (Tasks 1 and 2), The Pennsylvania State University
- Joshua Kapcsos, graduate research assistant (Task 1), The Pennsylvania State University
- Juliet Page, coinvestigator, subrecipient to Penn State, Volpe National Transportation Systems Center
- Kimberly A. Riegel, coinvestigator (Task 2), subrecipient to Penn State, Queensborough Community College, City University of New York
- Michael Rybalko, Joe Salamone, et al., Boom Supersonic [industrial partner]
- Brian Cook and Charles Etter, Gulfstream [industrial partner]

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, assessing community noise impact, and developing methods to assess the 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, field demonstrations, laboratory experiments, or theoretical studies; for example, see Maglieri et al. (2014).

Task 1 – Obtaining Confidence in Signatures, Assessing Metrics Sensitivity, and Adjusting for Reference Day Conditions

The Pennsylvania State University

This task has transitioned into the new ASCENT Project 57. Please see the 2020 report for ASCENT Project 57, *Support for supersonic aircraft en-route noise efforts in ICAO CAEP,* which describes developments on this Task.

Task 2 – Assessing Secondary Sonic Boom Propagation

The Pennsylvania State University
Queensborough Community College, City University of New York

Research Approach

Background

As both conventional "N-wave" (normal) boom and low-boom supersonic aircraft are getting closer to implementation, it is important to assess all aspects of the sonic boom noise that reaches the ground. This includes the need to more completely understand secondary sonic booms, when/why they occur, and the resulting signatures.

Most of the research done in the United States was completed in 1980 to understand the regular occurrence of secondary sonic booms observed along the New England coastline as a result of Concorde flights approaching New York. There are two main types of secondary sonic booms: Type I is the ground boom resulting from shock waves emanating off the top of the aircraft that refract downward for certain atmospheric conditions, and Type II is the boom that bounces off of the ground or water surface and is bent in the atmosphere to come back down to the ground a second time. In order to better predict the conditions that result in these secondary sonic booms, the variance in the atmospheric conditions, type of aircraft, and trajectory should be examined.

In the recent work for Project 41 in 2019, the original work of Rickley and Pierce [2] was recreated using the PCBoom [1] modeling software. The sound ray arrival locations, resulting from the PCBoom simulations, showed very good agreement with the original Rickley and Pierce arrival locations.

With the confidence that PCBoom is appropriately predicting the ray trajectories for secondary sonic booms, the work for this year was focused on predicting the arrival locations for a variety of atmospheric conditions and locations in the United states. The Climate Forecast System (CFS) v2 [3] was used to obtain weather conditions for different times and locations.

East Coast Concorde Results

In order to better understand the way that secondary booms behave for different seasons, the arrival locations were modeled covering several years for all twelve months with an average weather profile for each month. This allowed us to look for trends in the arrival of secondary sonic booms throughout the year to better understand when they would most likely be heard. In this simulation, the same trajectory for a New York City arrival of a Concorde was used. In addition, the Concorde pressure information built into PCBoom was used as the aircraft, as if Concorde were flying today. Meteorological data for the years 2012, 2014, 2016, and 2018 were obtained using the CFS v2 database. The profiles for February, a typical winter month, are shown for all four years in Figure 1. The profiles for July, a typical summer month, are shown for all four years in Figure 2. In these figures, the biggest difference between the summer and winter months is the high-altitude wind directions. Using these atmospheric profiles, the ray arrival locations for these years for February and July are shown in Figure 3 and Figure 4, respectively. It is clear from Figures 3 and 4 that in the winter months there are no secondary sonic boom arrivals, but in the summer months there are strong arrivals of both Type 1 and Type 2 secondary sonic booms. This is consistent across all four years that were simulated. Hence, one can conclude that these secondary sonic booms would be expected to occur every summer on an annual basis, if Concorde were still flying. The noise mitigation method used in the late 1970s was to push the deceleration of Concorde from supersonic to subsonic out further from the coastline, and that method would still be expected to work today.

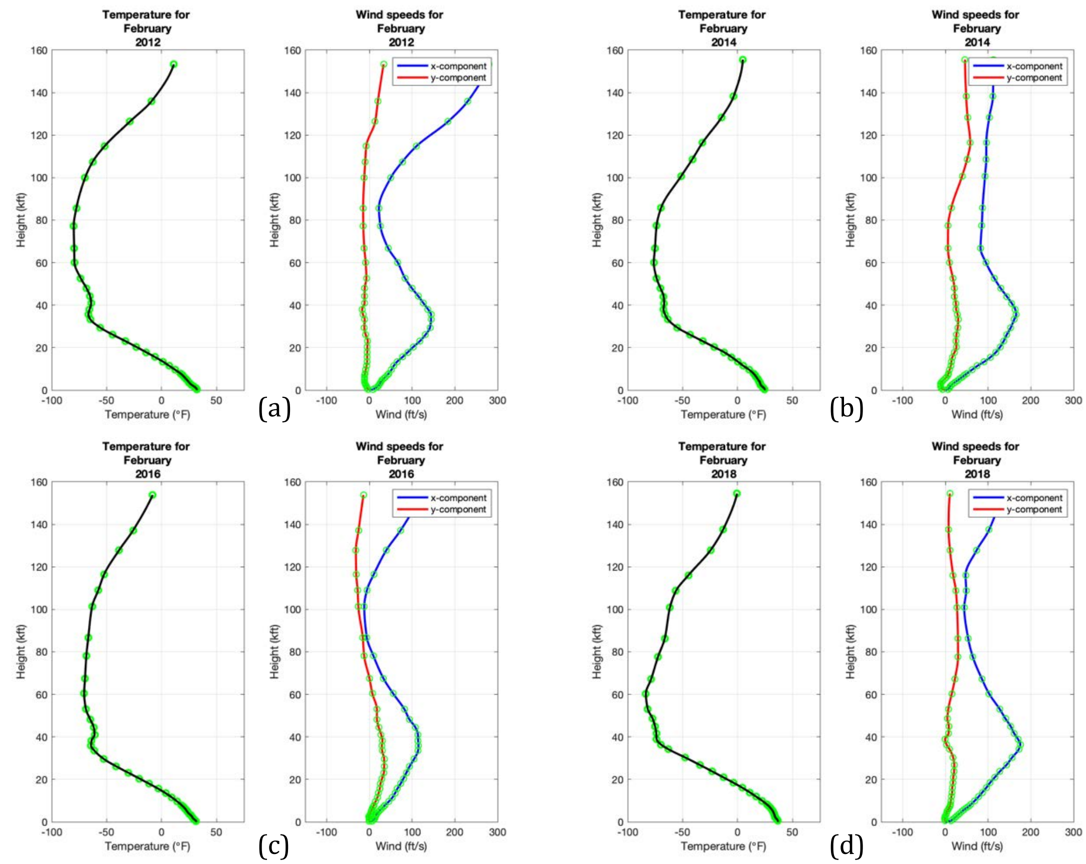

Figure 1. The monthly average temperature and wind speed profiles for February on the East Coast for (a) 2012, (b) 2014, (c) 2016, and (d) 2018.

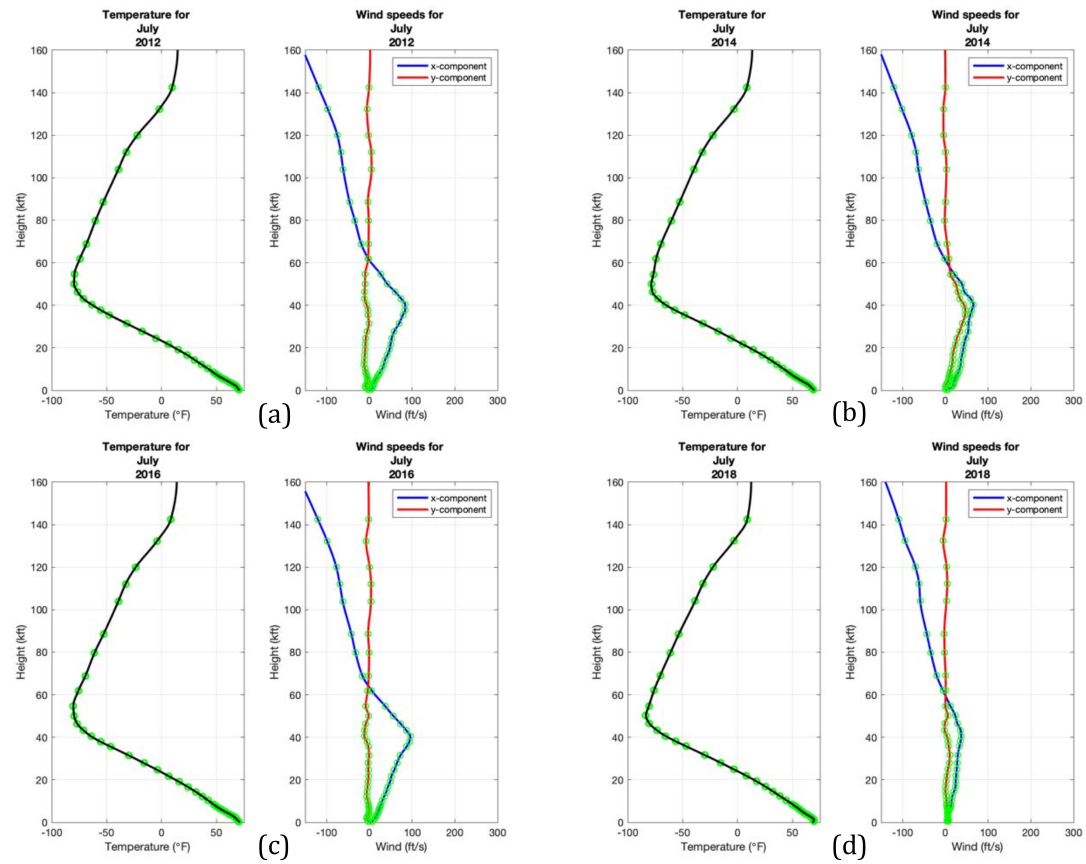

Figure 2. The monthly average temperature and wind speed profiles for July on the East Coast for (a) 2012, (b) 2014, (c) 2016, and (d) 2018.

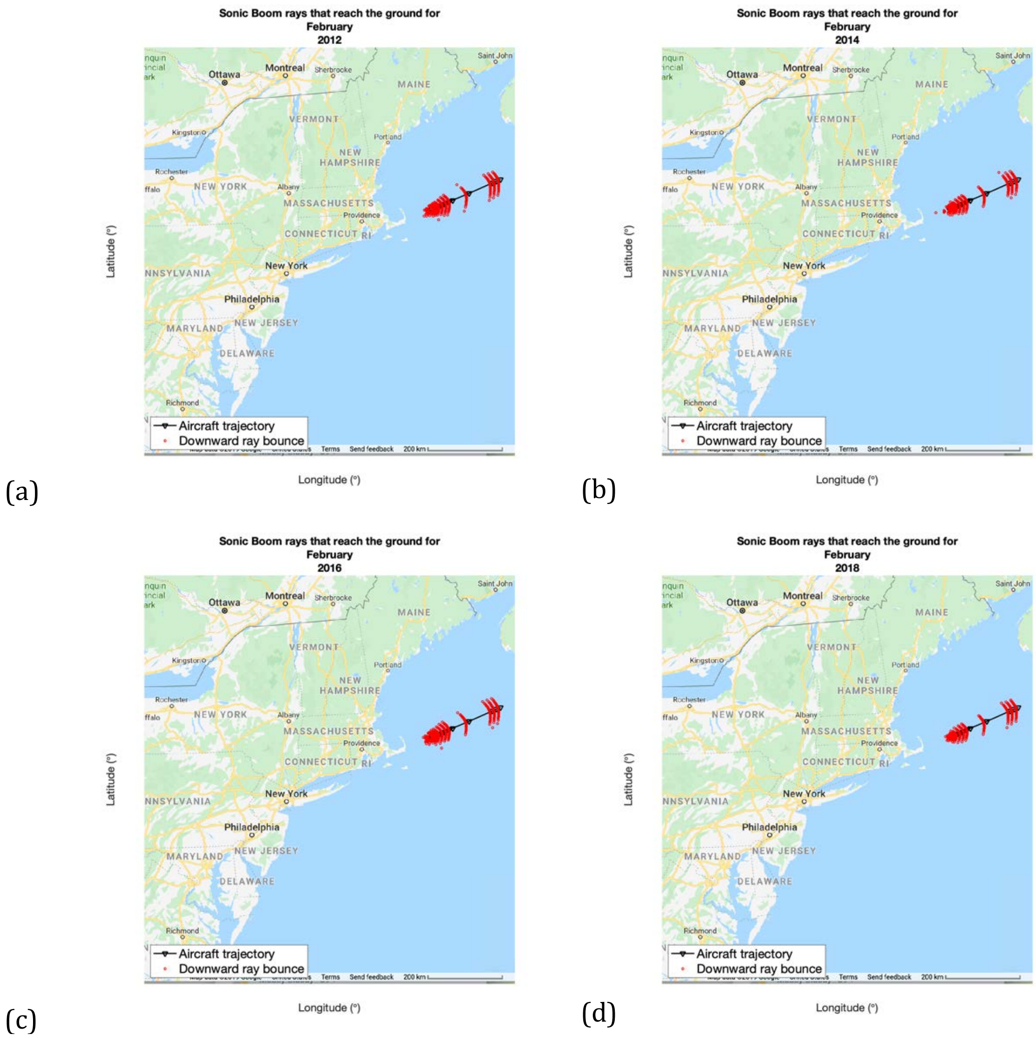

Figure 3. Ray arrival locations for a hypothetical Concorde aircraft approaching New York City for February in the years (a) 2012, (b) 2014, (c) 2016, and (d) 2018.

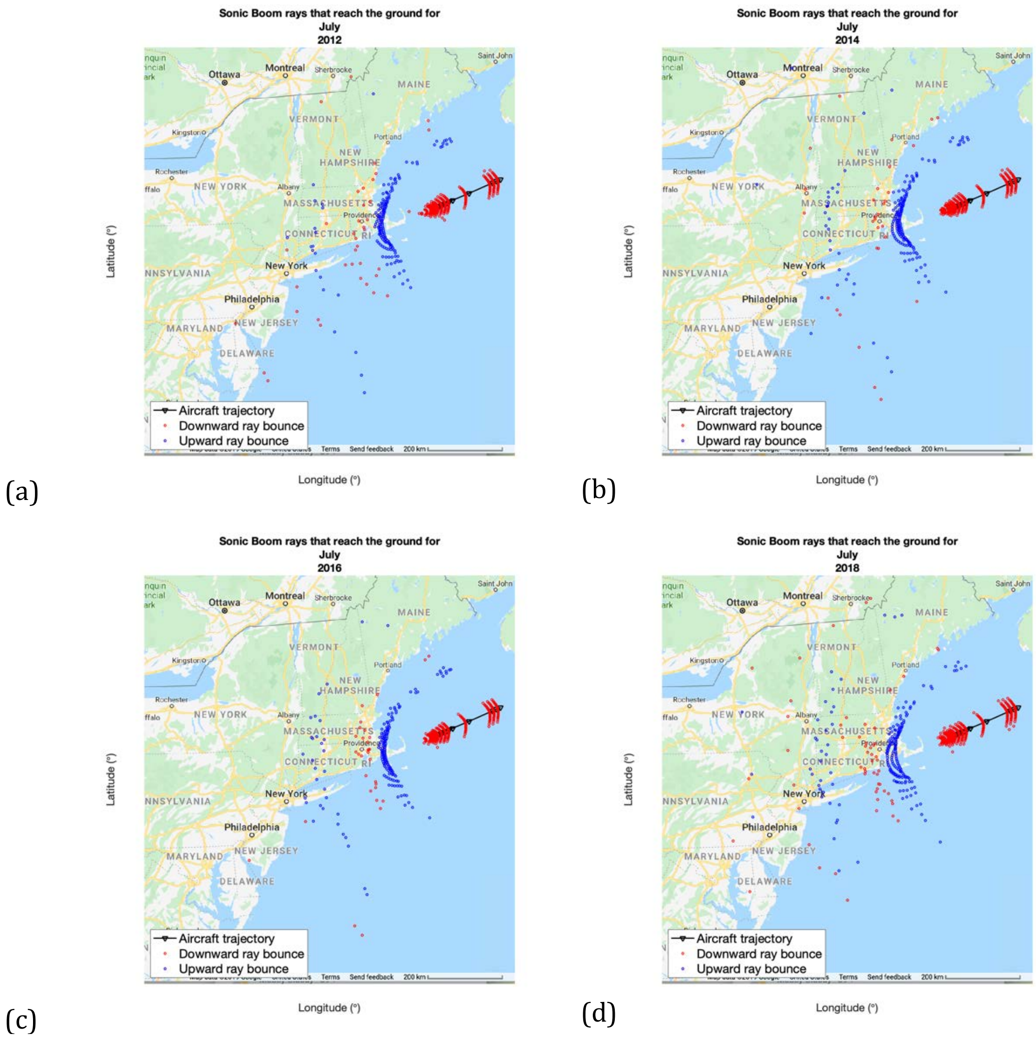

Figure 4. Ray arrival locations for a hypothetical Concorde aircraft approaching New York City for July in the years (a) 2012, (b) 2014, (c) 2016, and (d) 2018.

West Coast Concorde Results

The arrival locations of secondary sonic booms of a trajectory from a hypothetical Concorde approaching Los Angeles International Airport (LAX) from the south were modeled with PCBoom. Weather data for the West Coast was obtained from the CFS v2 for a location off the coast of LAX. This was used as the atmospheric conditions for PCBoom. Figure 5 shows the monthly average temperature and wind directions for February and July of 2018 for the West Coast. It should be noted that the wind directions are consistent with the East Coast in that during the summer months, there is a significant change in the wind between February and July where the winds come from the west during the winter and from the east during the summer. The trajectory as an approach to LAX was created using a similar speed profile (deceleration and waypoints) as for the East Coast study. The trajectory is shown in ray arrival plots in Figure 6. The consequence of the change in wind direction on the West Coast is that secondary booms impact the land during the winter months. While there are still secondary sonic booms that reach the Earth's surface, they are all impacting the ocean, far from the land, during the summer months. One notices the trend that the secondary sonic booms would more likely impact the West Coast during the winter months, while the impacts would more likely be in the summer months for the East Coast.

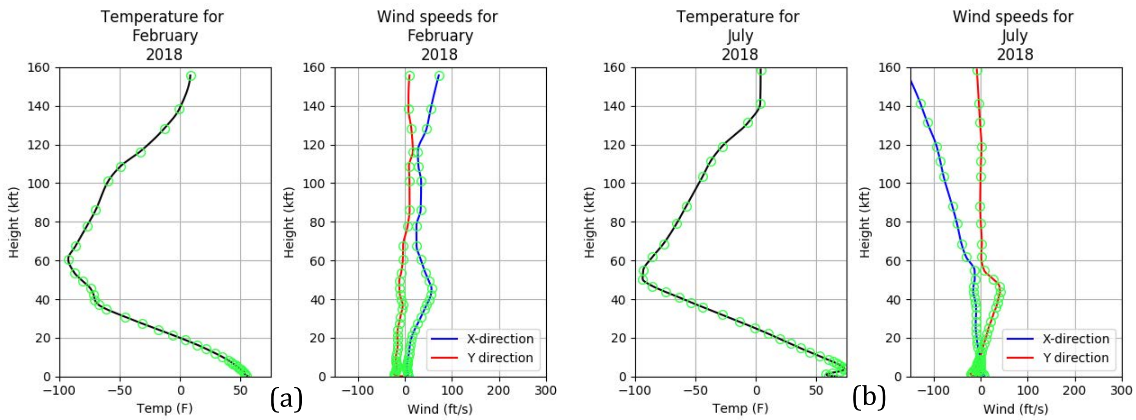

Figure 5. The monthly average temperature and wind speed profiles for (a) February and (b) July on the West Coast in 2018.

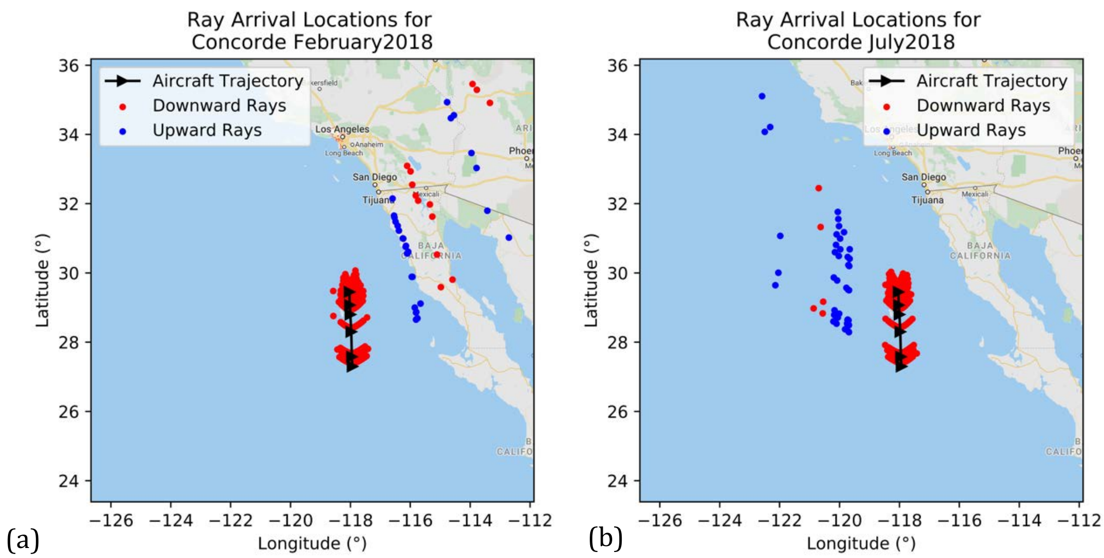

Figure 6. Ray arrival locations for a hypothetical Concorde aircraft approaching LAX for (a) February and (b) July in 2018.

Boom Supersonics Cylinder Data

Looking at an aircraft other than Concorde, Boom Supersonics provided computational fluid dynamics (CFD) data for their XB-1 demonstrator aircraft to the team at Penn State and Queensborough. These data were adapted to create cylinder input data for PCBoom. The ray arrival locations were successfully run with the cylinder option on PCBoom. The ray arrival locations are shown in Figure 7 for the same trajectory and atmospheric conditions provided in the original Rickley and Pierce report. The ray arrival locations are similar to the arrival locations for the Concorde for the same conditions.

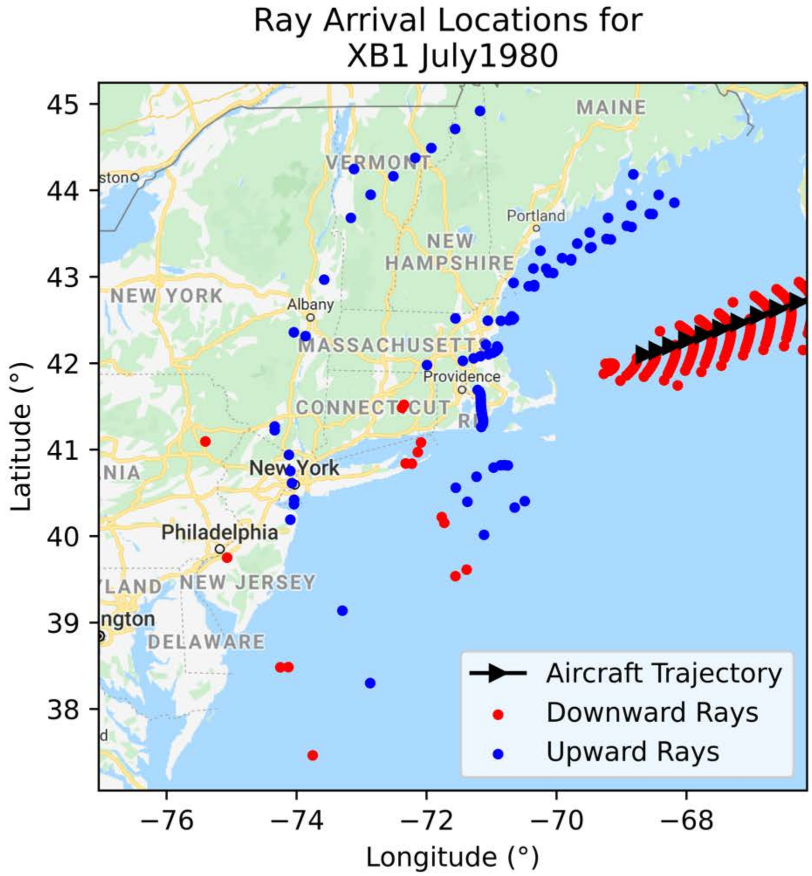

Figure 7. Predicted ray arrival locations for the XB-1 demonstrator aircraft approaching New York City, flying the original trajectory flown by Concorde, as documented in the Rickley and Pierce report.

Comprehensive Literature Review

In addition to the simulation subtasks, the project team also constructed a comprehensive literature review of known references related to the subject of secondary sonic boom. A summary paper, including 50 references, was presented at the December 2020 online meeting held by the European Acoustics Association. The original meeting was to take place in Lyon, France in April 2020, but it was delayed due to the Covid-19 pandemic and became the e-Forum Acusticum. The authors greatly appreciate the suggestions of colleagues acknowledged in the paper who provided feedback on initial drafts of the literature review to maximize the inclusion of all available references.

Milestone

The team successfully used Boom Supersonic CFD data, a requirement for in-kind cost sharing for Project 41.

Major Accomplishments

The team successfully demonstrated that secondary sonic booms are possible annually on both the United States' East and West Coasts and has shown that another aircraft produces ray arrival locations on the East Coast, similar to Concorde, if the same flight trajectory is flown. Furthermore, a comprehensive literature review on secondary sonic booms has been constructed and presented.

Publications

V. Sparrow and K. Riegel, "2020 literature review of secondary sonic boom," Written paper in Proc. 2020 e-Forum Acusticum (European Acoustics Association, Dec. 2020). This paper will be open-access, available online in 2021.

Outreach Efforts
None

Awards
None

Student Involvement
None for Task 2.

Plans for Next Period
The project team will investigate the pressure signatures at the ground for various aircraft to determine the pressure signatures on the ground. Changes to the current propagation models used in PCBoom for secondary sonic booms will need to be updated in order to accomplish this next step.

References
[1] Plotkin, K., Page, J., and Haering, E. (2007). Extension of PCBoom to over-the-top booms, ellipsoidal earth, and full 3-D ray tracing. AIAA 2007-3677, 13th AIAA/CEAS Aeroacoustics Conference
[2] Rickley, E. and Pierce, A. (1980). Detection and assessment of secondary sonic booms in New England. FAA-AEE-80-22, accessible as ADA088160
[3] Saha, S., et al. (2014). The NCEP Climate Forecast System Version 2. J. Climate, Vol. 27, 2185-2208, accessible as DOI: 10.1175/JCLI-D-12-00823.1