Project 057 Support for Supersonic Aircraft En-route Noise Efforts in ICAO CAEP

The Pennsylvania State University

Project Lead Investigator

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

University Participants

The Pennsylvania State University

- PI: Vic Sparrow, United Technologies Corporation Professor and Director, Graduate Program in Acoustics
- FAA Award Number: 13-C-AJFE-PSU Amendment 55
- Period of Performance: February 5, 2020 to August 4, 2021
- Tasks:
    1. Obtaining confidence in signatures, assessing metrics sensitivity, and adjusting for reference day conditions.
    2. Assessing secondary sonic boom propagation.

Project Funding Level

This project focuses on multiple Tasks at The Pennsylvania State University (Penn State) and its subcontractor Queensborough Community College. The FAA funding to Penn State in 2020–2021 is $200,000. Matching funds are expected to meet cost share on both Tasks. Boom Supersonic has pledged $100,000 and Gulfstream has pledged $100,000.

Investigation Team

- Victor W. Sparrow, PI (Task 1 and 2), The Pennsylvania State University
- Joshua Kapcsos, graduate research assistant (Task 1), The Pennsylvania State University
- 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, Charles Etter, Gulfstream [industrial partner]

Project Overview

We are on the verge of a true revolution in passenger aircraft development. Companies such as Boom Supersonic, AERION, Gulfstream Aerospace Corporation, Lockheed Martin, and others are reaching the point where they can build, and deliver to users', aircraft capable of flying supersonically in an environmentally responsible way. This will allow for decreased air transportation travel times, to the great benefit of everyone.

To introduce new supersonic aircraft, these vehicles must be certified as being quiet enough so as to not highly annoy the public. Preparing for such a certification process has been ongoing for several years in the FAA Office of Environment and Energy (AEE). Working with its international partners in the International Civil Aviation Organizations (ICAO)'s Committee for Aviation Environmental Protection (CAEP), FAA has been laying the groundwork for certification standards. The FAA efforts have been supported by both universities and other government agencies. Specifically, Penn State has supported FAA/AEE through Projects 8 and 24 in the PARTNER Center of Excellence (http://partner.mit.edu/) and in Projects 7, 41, and 42 more recently in the ASCENT Center of Excellence (https://ascent.aero/). Summaries of these research efforts can be found on the websites provided. Thus far, a group of six candidate metrics for sonic boom certification have been agreed upon in CAEP's Working Group 1 (Noise) Supersonic Task Group (SSTG). Several schemes for certification have been generated. A few schemes have been eliminated from further consideration, and others are currently being evaluated for possible implementation. Procedures have been proposed for acquiring and processing ground measurement of the sonic boom signatures, but all is still under discussion. The extent to which atmospheric conditions will affect the measurements and the requirements and role of numerical simulations of sonic booms propagating from the aircraft to the ground are being considered. One particularly tricky part is the influence of the atmosphere creating distortions in the sonic boom signatures, due to atmospheric turbulence, and the subsequent effects on the metric values. These are just a few of the gaps that need to be filled.

All of these topics are being worked, step by step, in FAA and in Working Group 1's SSTG. Recent efforts in ASCENT Project 041 are to support FAA with technical expertise with the development of the certification procedures, as well as to gain an initial understanding of secondary sonic booms. Secondary sonic booms, also known as over-the-top sonic booms, are the sound energy which travels upward at heights above the aircraft cruise altitude and land at distant locations. Secondary sonic booms are the reason that Concorde was requested to transition from supersonic to subsonic speeds at substantial distances before entering the continental United States. ASCENT Project 041 will be ending in 2020 (or soon thereafter) and ASCENT Project 57 has just begun, but there is still a lot more to do as an effort lasting over several more years will be required to move forward on certification standards for supersonic aircraft.

In 2020 and beyond, continued support for supersonic aircraft noise efforts will be necessary for FAA and its international partners to fill technical solution gaps and continue making progress toward certification procedures. Although other universities and industry will continue their focus on aircraft design and landing and takeoff (LTO) studies, it is essential to continue working on the sonic boom issues as these remain the greatest barrier for environmentally responsible supersonic aircraft. This new ASCENT Project will support the ongoing activities in ICAO CAEP and their Working Group 1 (Noise) with a focus on establishing supersonic aircraft en-route procedures and metrics for noise certification standards, and to support the interface with the ICAO Air Navigation Commission to address related noise issues.

In the 2020-2023 project period, the emphasis will be on continuing the support for supersonic aircraft en-route procedures. This includes the utilization of an agreed-upon reference day atmosphere, the establishment of techniques for incorporating measurement data and simulations into a draft certification procedure, and the consideration of off-design flight speed sonic booms, such as focus booms and acceleration booms. Support will also be provided for a more complete analysis of NASA's SonicBAT dataset and efforts on a methodology to remove the effects of atmospheric turbulence on measured sonic boom waveforms to support certification. The 2020-2023 research will also need to consolidate and process the results of research in 2019-2020 on the topic of secondary sonic booms that is a potential noise issue for initial supersonic airplanes. This material will be of particular interest to ICAO's Air Navigation Commission, since it could affect the operation of supersonic aircraft in the near-term. The project investigator, Dr. V. Sparrow, will also be available to assist the FAA in providing expert knowledge and scientific understanding on sonic booms, as requested, and to support the other CAEP committees, such as the Impacts and Science Group on their aircraft noise impacts activities.

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

The Pennsylvania State University

Objectives

ASCENT Project 57 is a transition from Project 41: *Identification of Noise Acceptance Onset for Noise Certification Standards of Supersonic Airplanes*; 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. The objective of this Task is to support the FAA in the development of technical standards for civil supersonic aircraft under ICAO CAEP. This effort provides FAA with technical noise expertise regarding the development of noise certification standards for future civil supersonic passenger aircraft, primarily in the area of en-route noise (sonic boom) minimization and/or abatement.

Task 1 in ASCENT Project 57 focuses on research initiatives needed to move toward the development of a low-boom supersonic en-route noise certification standard. An objective was to simulate the effects of turbulence within various planetary boundary layer heights above the ground. Additionally, Penn State was motivated to compare the results and evaluate agreement with data produced by organizations that use different turbulence tools.

Research Approach

Background

The Japan Aerospace Exploration Agency (JAXA) recently utilized the SPnoiseSB tool to simulate the effects of turbulence on NASA's concept aircraft C609 shaped sonic boom through various planetary boundary layer heights. During simulation, JAXA used the atmospheric conditions of the SonicBAT (Sonic Booms in Atmospheric Turbulence) project's Flight 5 that occurred on July 14, 2016 at the Armstrong Flight Research Center (AFRC). Simulated boundary layer heights included 268.2, 411.4, and 1026.7 meters. It is important to consider various boundary layers because these heights are determined by the point at which warm air begins to experience negative buoyancy, which depends on rapid increase in temperature and water vapor content. As one of the goals of Task 1 is to determine agreement with the results of other organizations that use different turbulence tools, Penn State was motivated to run similar simulations in order to compare to those of JAXA. NASA provided Penn State with sound metric analyses on JAXA data, and JAXA supplied additional databases.

Turbulence Modeling

The computational tool that Penn State used above the planetary boundary layer was the PCBoom 6.7.1.1 sonic boom propagation software. PCBoom was developed by kbrWyle and is maintained in part by NASA, and version 6.7.1.1 was supplied to Penn State in August of 2019. Penn State matched the SonicBAT flight conditions used for the PCBoom portion above the boundary layer to those used by JAXA. The shaped sonic boom was propagated in PCBoom from a cruise altitude of 50,000 ft to the top of the planetary boundary layer. The signature outputs of PCBoom were quite smooth in each case, since the enhanced BURGERS algorithm was utilized, incorporating the effects of molecular relaxation absorption. The PCBoom output signatures at the top of the planetary boundary layer was then fed as input into the turbulence tool. Because different tools were used both above and below the planetary boundary layer and because the chosen turbulence tool does not take a ground reflection factor into account, the ground reflection factor was turned off in the PCBoom portion and instead applied during post-processing.

Penn State used the 2-dimensional version of KZKFourier as the turbulence tool to propagate the sonic boom through the planetary boundary layer to the ground. The KZKFourier code was developed by post-doctoral scholar Trevor Stout as a component of his 2018 Ph.D. dissertation, and the code uses an augmented nonlinear Khokhlov-Zabolotskaya-Kuznetsov (KZK) propagation equation that includes nonlinearity, diffraction, and absorption in directional sound beams. KZKFourier was designed to implement the Ostashev and Wilson (O&W) model throughout the turbulent boundary layer, which considers temperature and wind fluctuations corresponding to scalar and vector turbulence, respectively. The latter includes wind shear and buoyancy effects. The O&W model varies turbulence by defining length scale and root mean square (RMS) magnitude as a function of height, gradually changing which parts of the logarithmically spaced wavenumber spectrum are accentuated as the boom approaches the ground. The code features two Von Karman spectra equations, one for the energy spectra of the temperature (scalar) fluctuations and one for the wind (vector) fluctuations, and turbulent fields are produced by the Random Fourier Modes method. A binary switch to turn off the O&W model is included in the KZKFourier code; this switch instead prescribes a single length scale and RMS magnitude at all heights. The code does not include profiles for humidity and other ambient quantities.

Parameters

Because KZKFourier does not include profiles for ambient atmospheric quantities, the relative humidity, temperature, and ambient pressure for the turbulence portion were extracted from the lowest altitude in the SonicBAT Flight 5 PCBoom atmospheric file provided by NASA. Penn State utilized these files in order to match the atmospheric parameters used by JAXA. The ray angle was determined by the angle of incidence of the output of the PCBoom portion and was held constant throughout the turbulence portion. KZKFourier generates atmospheres using random seeds, which were used for turbulence conditions 1 to 10. The amount and spacing of virtual microphones were set to correspond to JAXA parameters as well. KZKFourier output 100 ground pressure waveforms along the virtual microphone array to be plotted per JAXA's turbulence condition, but the output files are finer and had been prescribed as 4097 virtual microphones in each array.

Single Length Scale and RMS Magnitude without Temperature Fluctuations

In order to match JAXA conditions, the temperature fluctuation was initially not considered and the O&W model was turned off with the KZKFourier binary switch, prescribing a single length scale and RMS magnitude at all heights, as the tool used by JAXA did not take these factors into consideration. Penn State plotted 100 ground pressure waveforms for each of the three planetary boundary heights for turbulence condition 1, which are given below in Fig. 1. The plots for the latter nine turbulence conditions are visually similar and are therefore not shown. Because the O&W model was turned off and temperature fluctuation was not considered, the variability is not easily seen. The first plot features a magnified section to more clearly observe the small variation between ground pressure waveforms.

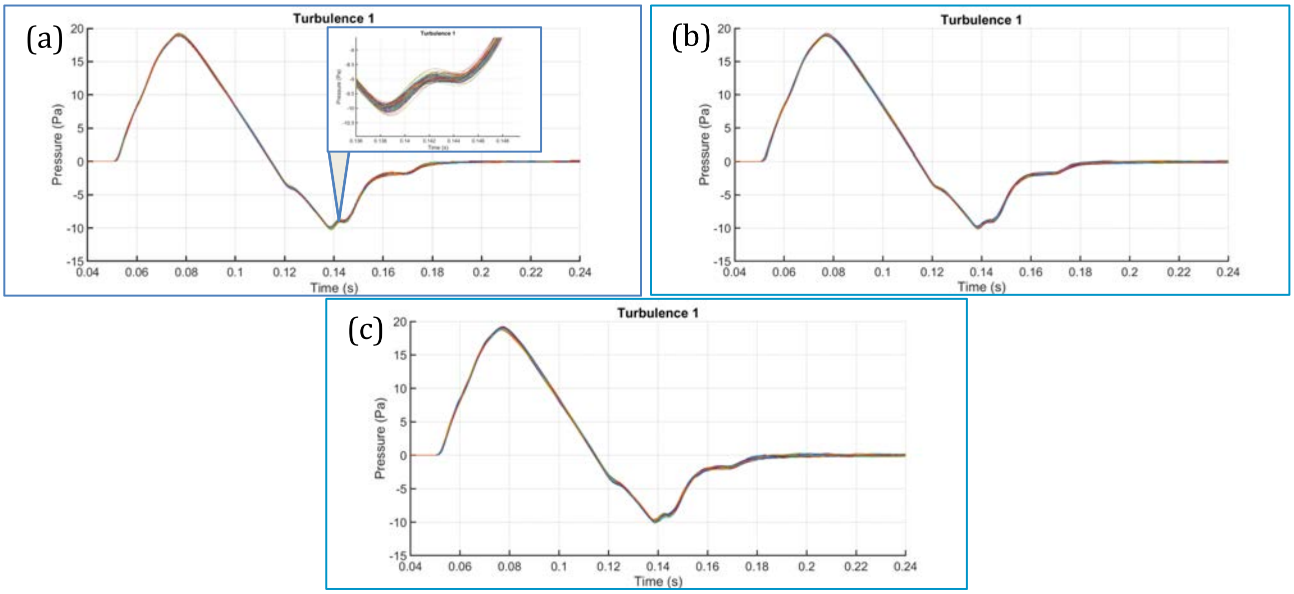

Figure 1. Plots of 100 ground pressure waveforms in Pa for turbulence condition 1 after propagation through boundary layer heights of 268.224 m (a), 411.38 m (b), and 1026.7 m (c) with single length scale and RMS magnitude.

In addition to plotting ground pressure waveforms, NASA ran analyses on the JAXA sound metric database. Penn State ran similar analyses, a portion of which are given below in Tables 1 and 2 that list the Steven's Mark VII Perceived Level (PL) and Indoor Sonic Boom Annoyance Predictor (ISBAP) sound metrics, respectively. Sound exposure level (SEL) metrics A through E were also calculated and meet the ANSI/ASA S1.42 standard. The tables feature the mean, standard deviation, minimum, median, and maximum values of the applied sound metric of the 100 ground pressure waveforms for each of the 10 turbulence conditions and zero turbulence condition; condition 0 corresponds to no turbulence. It should be noted that KZKFourier does not include amplitude changes to account for geometrical spreading, which can reduce boom pressure amplitude by about 2% at AFRC. As such, the below PL output was corrected to account for geometric spreading by subtracting the difference between PCBoom and KZKFourier ground level realizations under zero turbulence.

Table 1. List of PLdB per turbulence analysis calculated via KZKFourier simulations with single length scale and RMS magnitude. Results have been corrected to account for geometric spreading.

	268.224 m BL					411.38 m BL					1026.7 m BL				
Turb.	Mean	SD	Min	Med.	Max	Mean	SD	Min	Med.	Max	Mean	SD	Min	Med.	Max
0	67.02	-	67.02	67.02	67.02	67.02	-	67.02	67.02	67.02	67.02	-	67.02	67.02	67.02
1	66.84	0.61	65.39	66.87	68.54	66.77	0.65	65.32	66.73	68.36	66.58	0.65	64.7	66.64	67.88
2	66.85	0.58	65.42	66.83	68.30	66.76	0.85	64.76	66.79	68.43	66.63	0.81	64.42	66.52	68.55
3	66.89	0.50	65.61	66.91	68.12	66.81	0.53	65.44	66.85	68.19	66.63	0.52	65.43	66.58	67.92
4	66.80	0.81	64.44	66.69	68.75	66.73	0.89	64.23	66.8	68.72	66.52	1.16	64.03	66.56	69.41
5	66.84	0.65	64.72	66.87	68.60	66.82	0.63	65.26	66.83	68.63	66.61	0.74	65.02	66.59	68.59
6	66.79	0.75	65.10	66.77	68.48	66.74	0.82	64.61	66.63	68.44	66.63	0.80	65.24	66.52	68.93
7	66.82	0.60	65.11	66.87	68.56	66.84	0.56	65.46	66.90	68.06	66.57	0.56	65.1	66.61	67.67
8	66.86	0.64	65.43	66.84	68.53	66.75	0.70	64.68	66.80	68.35	66.58	0.83	64.44	66.59	68.97
9	66.83	0.61	65.07	66.85	68.41	66.77	0.67	65.18	66.86	68.22	66.61	0.72	65.21	66.61	68.17
10	66.82	0.72	64.75	66.85	68.49	66.76	0.83	64.79	66.77	68.70	66.54	0.89	64.10	66.49	69.18

The ISBAP sound metric analysis is provided below in Table 2. Note that these ISBAP results were not corrected to account for geometric spreading.

Table 2. List of ISBAP per turbulence analysis calculated via KZKFourier simulations with single length scale and RMS magnitude. Geometric spreading is not considered.

	268.224 m BL					411.38 m BL					1026.7 m BL				
Turb.	Mean	SD	Min	Med.	Max	Mean	SD	Min	Med.	Max	Mean	SD	Min	Med.	Max
0	82.80	-	82.80	82.80	82.80	82.75	-	82.75	82.75	82.75	82.45	-	82.45	82.45	82.45
1	82.64	0.37	81.71	82.65	82.57	82.56	0.38	81.65	82.56	83.48	82.10	0.40	80.96	82.12	82.86
2	82.66	0.35	81.74	82.66	83.47	82.56	0.49	81.26	82.58	83.51	82.15	0.48	80.97	82.09	83.44
3	82.68	0.30	81.86	82.68	83.38	82.59	0.31	81.86	82.59	83.35	82.14	0.31	81.52	82.11	82.86
4	82.63	0.49	81.15	82.56	83.91	82.53	0.52	81.04	82.56	83.75	82.08	0.70	80.53	82.07	83.84
5	82.65	0.40	81.33	82.67	83.68	82.59	0.38	81.66	82.64	83.66	82.14	0.44	81.08	82.16	83.21
6	82.62	0.44	81.67	82.62	83.64	82.54	0.48	81.34	82.53	83.50	82.16	0.51	81.26	82.09	83.53
7	82.62	0.35	81.58	82.63	83.59	82.59	0.32	81.74	82.61	83.30	82.11	0.33	81.25	82.15	82.78
8	82.66	0.39	81.79	82.65	83.69	82.55	0.42	81.39	82.57	83.45	82.10	0.49	80.73	82.08	83.52
9	82.64	0.37	81.46	82.64	83.62	82.56	0.38	81.50	82.61	83.42	82.13	0.45	81.23	82.13	83.23
10	82.64	0.43	81.35	82.63	83.63	82.55	0.49	81.42	82.56	83.79	82.09	0.53	80.66	82.09	83.89

The above results were compared to the NASA analysis of JAXA results, and it was concluded that the Penn State data agreed closely with JAXA regarding means, but the standard deviations were higher than those of JAXA due to tool differences. The standard deviations of the Penn State results were all well within one standard deviation, and unincluded histograms and normal probability plots showed the turbulence conditions were approximately normally distributed for PL and ISBAP. The mean sound metric value decreased with increased boundary layer height, and the standard deviations increased with increased boundary layer height, both of which are intuitive because propagation over a longer distance results in more exposure to turbulence and its formulated randomness.

Varied Turbulence as Function of Height with Temperature Fluctuations

As previously noted, the O&W model can be turned on or off using a binary switch in KZKFourier in order to vary turbulence as a function of height, in which higher wavenumbers become more important near the ground. Temperature fluctuations can also be prescribed in the KZKFourier code. Because there was good agreement between KZKFourier simulations and field measurement data for metric variability for N-waves during the SonicBAT project, Penn State performed a similar analysis with the shaped signature of the C609 concept aircraft, diverging from the previous JAXA scheme by turning on the O&W model and prescribing temperature fluctuations. Friction velocity, mixed-layer velocity scale, and surface layer temperature scale values required for the O&W model execution in KZKFourier match the parameters used for 2D and filter validation simulations as listed in the Stout thesis and SonicBAT contractor report. Again, flight conditions for the PCBoom portion above the boundary layer were the same used by JAXA and Penn State in previous runs.

Plots of 100 ground pressure waveforms for each of the three planetary boundary heights for turbulence condition 1 are given below in Fig. 2. The variability produced by the O&W model are very visible in comparison to the previous runs in which a single length scale was used. The plots for the latter nine turbulence conditions are visually similar to the below provided plots and are therefore not shown.

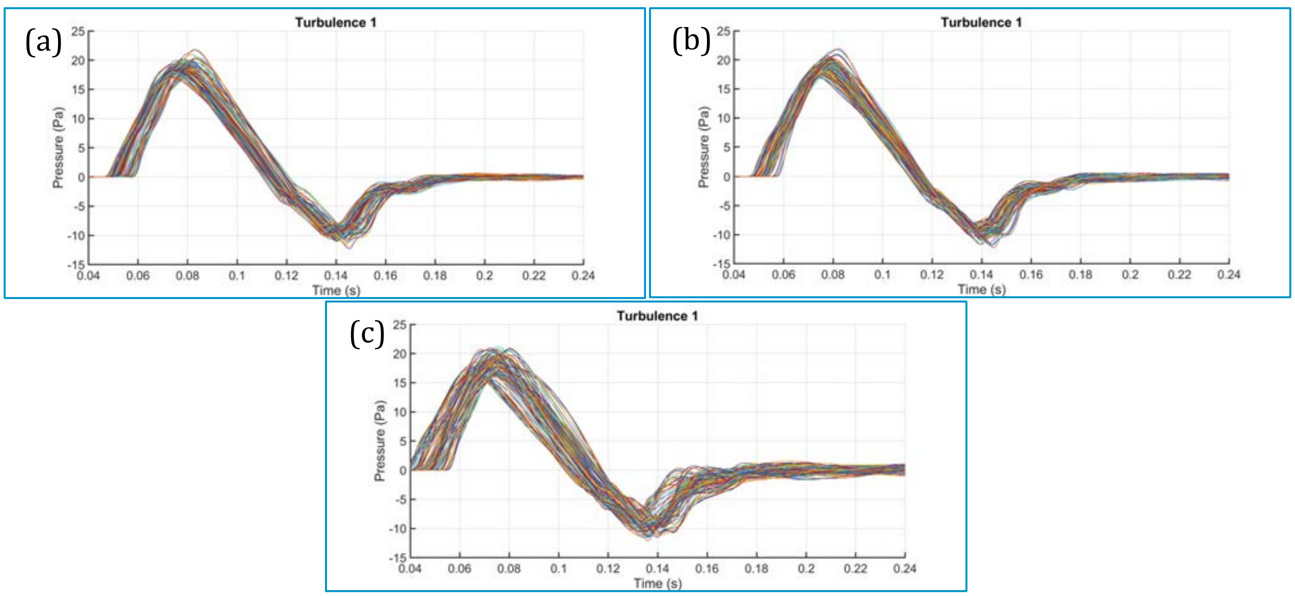

Figure 2. Plots of 100 ground pressure waveforms in Pa for turbulence condition 1 after propagation through boundary layer heights of 268.224 m (a), 411.38 m (b), and 1026.7 m (c) with O&W model and temperature fluctuations.

In addition to plotting ground pressure waveforms, Penn State again ran sound metric analyses, a portion of which are given below in Tables 3 and 4 in lists of the PL and ISBAP sound metrics, respectively. SEL metrics A through E were also calculated and meet the ANSI/ASA S1.42 standard. Neither of the below tables were modified to account for geometric spreading. The tables feature the mean, standard deviation, minimum, median, and maximum values of the applied sound metric of all 4097 ground pressure waveforms of the fine microphone array for each of the 10 turbulence conditions and zero turbulence condition.

Table 3. List of PLdB per turbulence analysis calculated via KZKFourier simulations with the O&W model and temperature fluctuations. Geometric spreading is not considered.

	268.224 m BL					411.38 m BL					1026.7 m BL				
Turb.	Mean	SD	Min	Med.	Max	Mean	SD	Min	Med.	Max	Mean	SD	Min	Med.	Max
0	67.81	-	67.81	67.81	67.81	67.76	-	67.76	67.76	67.76	68.14	-	68.14	68.14	68.14
1	67.27	1.76	63.05	67.33	71.99	67.11	1.97	62.01	67.00	72.89	66.65	2.59	58.01	66.72	75.69
2	67.39	1.52	64.10	67.35	71.53	67.19	1.88	62.32	67.11	71.90	66.70	2.60	60.50	66.87	74.00
3	67.26	1.87	62.98	67.25	72.97	67.03	2.16	62.37	66.74	73.36	66.41	2.88	60.31	65.93	75.00
4	67.28	1.83	63.21	67.38	73.57	66.86	2.47	61.38	66.63	75.02	66.35	3.09	59.93	65.94	74.02
5	67.31	1.80	62.70	67.44	71.44	67.26	2.26	60.42	67.64	72.87	66.33	3.21	58.86	66.62	73.78
6	67.27	1.88	61.78	67.19	72.16	66.89	2.60	60.62	66.90	73.23	66.03	3.62	56.26	65.87	76.77
7	67.33	1.66	63.26	67.34	72.53	67.01	2.22	62.34	67.02	73.46	66.36	3.09	58.66	66.40	73.77
8	67.37	1.55	63.01	67.42	70.77	67.20	1.77	63.62	67.13	72.32	66.86	2.17	62.55	66.85	72.60
9	67.21	1.95	62.00	67.09	72.70	66.71	2.76	59.86	66.37	73.19	66.20	3.44	57.10	66.08	75.40
10	67.24	1.91	62.56	67.18	72.51	67.03	2.21	61.51	67.08	73.46	66.69	2.71	57.63	66.78	74.50

Table 4. List of ISBAP per turbulence analysis calculated via KZKFourier simulations with the O&W model and temperature fluctuations. Geometric spreading is not considered.

	268.224 m BL					411.38 m BL					1026.7 m BL				
Turb.	Mean	SD	Min	Med.	Max	Mean	SD	Min	Med.	Max	Mean	SD	Min	Med.	Max
0	82.82	-	82.82	82.82	82.82	82.77	-	82.77	82.77	82.77	82.89	-	82.89	82.89	82.89
1	82.40	1.24	79.62	82.35	86.11	82.26	1.37	78.86	82.16	86.65	81.79	1.94	76.20	81.84	88.55
2	82.47	1.10	80.26	82.35	85.65	82.32	1.29	79.05	82.16	85.32	80.85	3.62	69.95	81.84	86.99
3	82.41	1.27	79.45	82.42	86.19	82.23	1.45	78.74	82.18	86.58	81.60	2.14	77.26	81.26	87.74
4	82.42	1.30	79.52	82.49	86.96	82.10	1.81	78.08	81.96	88.16	81.61	2.22	77.75	81.27	87.16
5	82.43	1.30	79.15	82.51	85.70	81.89	1.91	76.90	82.11	85.54	81.48	2.55	75.03	81.72	87.08
6	82.42	1.31	78.66	82.37	85.86	82.13	1.91	77.54	82.18	86.65	81.27	2.83	73.81	81.40	89.90
7	82.45	1.11	79.80	82.46	86.22	82.22	1.50	78.84	82.28	86.81	81.58	2.34	76.14	81.60	86.98
8	82.47	1.01	79.47	82.50	84.82	82.33	1.23	79.37	82.26	86.08	81.91	1.62	78.20	81.84	85.92
9	82.38	1.31	78.91	82.32	85.81	82.02	1.91	77.20	81.95	86.12	81.43	2.68	74.27	81.34	88.41
10	82.39	1.28	79.01	82.40	85.90	82.21	1.59	77.89	82.33	86.71	81.76	2.17	75.13	81.94	87.73

The standard deviations of the above tables were much higher than those of the previous runs as temperature fluctuations were considered and the O&W model was switched on in KZKFourier; the O&W model prescribed more turbulence that resulted in more variation. Similar to the previous runs, the standard deviations increased with increase in planetary boundary layer height, while mean sound metric decreased with increase in planetary boundary layer height.

Milestone

The impact of atmospheric turbulence on various planetary boundary layer heights was assessed in two different turbulence modeling schemes.

Major Accomplishments
ASCENT Project 57 Task 1 has determined that sonic boom metrics are affected differently given the signature variability introduced by atmospheric turbulence, which may prove useful in sonic boom certification of supersonic aircraft.

Publications
None

Outreach Efforts
A summary of the procedure and findings of Task 1 were presented in the form of a virtual poster during the 2020 Fall Workshop of the Penn State Center for Acoustics and Vibration.

Awards
None

Student Involvement
Joshua Kapcsos was the Penn State graduate research assistant who worked on ASCENT Project 57 during the 2019-2020 academic year. In addition to the above research, he has been undertaking direct numerical comparisons of the fluctuation and spectral equations of different turbulence tools.

Plans for Next Period
Additional simulations and corresponding recommendations regarding the potential sonic boom metrics for inclusion in a certification procedure will be conducted. Because sonic boom metrics are affected differently given the signature variability introduced by atmospheric turbulence, turbulent sonic boom propagation prediction software/code certification will be continued. Differences between turbulence models should be further evaluated for future agreement. The effects of temperature, wind, and humidity profiles on certification schemes will also be further studied. Task 1 of Project 57 will continue examining sonic boom propagation through turbulence for possible application to supersonic aircraft certification.

References
[1]T. Stout, "Simulation of N-Wave and Shaped Supersonic Signature Turbulent Variations," Pennsylvania State University, Ph.D. Dissertation, December 2018.
[2]V. Ostashev, D. Wilson, *Acoustics in Moving Inhomogeneous Media* (2nd ed.), CRC Press, Boca Raton, FL, 2015.
[3]K. Bradley, *et al.*, "Sonic Booms in Atmospheric Turbulence (SonicBAT): The Influence of Turbulence on Shaped Sonic Booms" (NASA/CR-2020-220509), National Aeronautics and Space Administration, Armstrong Flight Research Center, Edwards, CA, 2020.

Task 2 – Assessing Secondary Sonic Boom Propagation
The Pennsylvania State University
Queensborough Community College / City University of New York

Information regarding this Task appears in the 2020 report for ASCENT Project 041: *Identification of Noise Acceptance Onset for Noise Certification Standards of Supersonic Airplanes*. In future years, information on this Task will appear in the annual report on Project 57.