Project 062 Noise Model Validation for AEDT

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The Pennsylvania State University

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Georgia Tech has agreed to a total of $235,000 in matching funds. This total includes salaries for the project director, research engineers, and graduate research assistants; and computing, financial, and administrative support, including meeting arrangements. Georgia Tech has also agreed to provide tuition remission for the students, paid for by state funds.

PSU's industrial partner, Spire Global (spire.com), is providing cost-share funds at a level of $115,000 in the form of meteorological data and research support. The point of contact for this cost-share is Mr. Cromarty [+1 (650) 300-9997, william.cromarty@spire.com].

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Project Overview

The focus of this project is to assess the accuracy of the Aviation Environmental Design Tool (AEDT) in estimating noise both in the vicinity of airports as well as further afield. The foundation of AEDT noise modeling is based on the Integrated Noise Modeling (INM) tool, which has undergone a number of validation and verification efforts in the past, specifically at the Denver International Airport (DIA), and it has shown continually improving agreement of modeling with measurement data. During the development of AEDT, multiple algorithm updates have occurred, and this project seeks to quantify the new noise modeling capabilities based on comparison to field measurement data from DIA and other airport monitoring systems. The research team will develop a detailed model validation plan, review the plan with the FAA for concurrence, execute the plan, and make recommendations for future AEDT development. The research, once completed, is expected to provide a noise model validation benchmark that can be used not only to respond to questions on AEDT noise prediction accuracy, but also to allow the tool development team to prioritize further development of modeling features and enhancements. The research team will also collaborate with The Pennsylvania State University (PSU) on the assessment of the noise propagation assumptions and the use of higher-fidelity weather data.

Introduction and Background

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The last decade has witnessed demand for air passenger services grow with a long-term average of over 5% in terms of revenue passenger miles (RPK) [1]. To mitigate the impact of this growth in aviation on the environment and to maximize the economic benefit that can be achieved from added efficiency and performance, NASA's Environmentally Responsible Aviation (ERA) project has suggested aggressive goals [2]. Within these set of goals is a target to reduce the noise emissions created by aviation over the 2015, 2020, and 2025 timeframes. The first step in mitigating noise emissions is having the capability to model them with a high level of accuracy. The FAA's AEDT (https://aedt.faa.gov/) is one of the most advanced capabilities for both modeling aircraft operations and computing the associated environmental metrics. AEDT is a software system that models aircraft performance in space and time to estimate fuel consumption, emissions, noise, and air quality consequences. AEDT's primary objective is to facilitate the environmental review of federal actions associated with changes to airport, airspace, and other applicable aviation activity.

Several past efforts have studied the improvement of modeled procedures in AEDT or the comparison between AEDT capabilities and real-world operational data. Noise abatement departure procedures (NADPs) are commonly used for mitigation of community noise either closer to the airport or further afield. Lim et al [3] provided a set of 20 different NADP profiles suitable for modeling a large variety of operations that are typically observed in the real world. Behere et al. [4-5] focused on quantifying impacts of such NADP profiles on noise modeling and identified the most representative NADP profiles. AEDT has also been used in creation of alternative rapid noise modeling tools [6-7], comparing aviation environmental impact mitigation strategies [9], and various other community noise quantification studies [9-11]. Other efforts have focused on using large amounts of real-world data to produce reduced order models for rapid computation of noise impacts [12] or for estimating the impact of average types of operations at different airports [13].

Prior studies related to noise model validation date back to AEDT's predecessor, the Integrated Noise Model (INM). Several prior efforts have focused on validation of AEDT or INM to quantify the level of agreement between model prediction and data recorded from actual operations. Page et al. [14] investigated a 1997 dataset from Denver International Airport (KDEN) to determine how INM's prediction accuracy changed with different thrust prediction methods. They found that manufacturers' look-up values of normalized thrust were the most accurate. They then used this information to improve the noise-power-distance (NPD) curves in INM from historical manufacturer data. In 2006, Forsyth and Follet [15] used the same 1997 KDEN data with an interest in updating INM's database with an emphasis on higher altitudes. Spectral classes were created as a result to correct the NPD information with respect to SAE AIR-1845 atmospheric absorption. In another study performed with the 1997 KDEN data, Plotkin et al. [16] studied options to further enhance the modeling capability by accounting for effects of weather and terrain.

Since its introduction by the FAA in 2015, numerous studies have been performed on AEDT. Hobbs et al. [17] proposed an easily implementable method for including ground cover effects on noise propagation calculations by using algorithms originally implemented in the Advanced Acoustic Model (AAM) [14]. These algorithms use optical straight-ray theory as adapted for acoustics to model noise propagation in addition to the Fresnel ellipse method. This was shown to improve noise propagation calculations compared with empirical data after using data from Portland International Airport (PDX), San Francisco International Airport (SFO), and Oakland International Airport (OAK). Downing et al. (2019) investigated a method for including terrain and manufactured structural effects in AEDT's noise propagation calculations in 2019. Three separate models were evaluated with respect to their ability to accurately predict how buildings and barriers affect aircraft noise: Traffic Noise Model (TNM) [19], SoundPLAN 7.4 (which uses ISO 9613-2), and the National Cooperative Highway Research Program's Reflection Screening Tool. After validation using data from Los Angeles International Airport (LAX) and Long Beach Airport (LGB), the TNM method was recommended as the best option because its noise calculations have similar variability and consistency as AEDT's baseline calculations. In previous research by Gabrielian et al. [20], an automated framework was demonstrated for validation of noise modeling capabilities within AEDT using real-world flight and noise monitor data. In another work, the authors studied AEDT's noise prediction capability while using high-fidelity weather data [21].

The rest of this report provides information on noise modeling data sources, AEDT assumptions, and automation capabilities developed for the current work. It also discusses the results generated for the bulk flight operations modeled along with any particular or aggregate insights.

Noise Modeling in AEDT

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System-level noise modeling in this report follows the procedure detailed in previous work by the authors [20]. Two important elements to this modeling are summarized here for completeness: (A) the data sources utilized during modeling, and (B) the modeling assumptions and alternatives available for each assumption.

Data Sources Utilized

Several data sources of different fidelity can be utilized for noise modeling, ranging from simple ground-based radar observations to data fusion from multiple sensors on an aircraft itself. The two main datasets that are relevant for this paper are described below.

1. **Flight Operational Quality Assurance (FOQA)** data consists of data recorded by the airline operating the flight. The basis for the FOQA program is laid out by FAA Advisory Circular 120-82, which states "The value of FOQA programs is the early identification of adverse safety trends that, if uncorrected, could lead to accidents" [22]. To this effect, FOQA systems record large amounts of data at one recording per second (i.e., 1 Hz), with these data having been used for a number of safety-related applications in prior work [23-24]. The important elements of the FOQA data for this paper relate to the detailed time history of parameters such as altitude, speed, thrust, weight, configuration (flaps, gear), and so on, for each flight that is modeled in AEDT.
2. **Noise Monitoring Data** contains five key parameters: A unique flight ID, noise monitor locations, class of noise reading, sound exposure level (SEL), and L_max metrics of associated noise events. The flight ID in the noise monitor data allows flights to be matched to the appropriate flight from FOQA data, thereby matching the aircraft configuration and the time of the noise event with the noise metric value. The class of the noise reading identifies the confidence with which the noise reading has been matched with the corresponding flight ID. The highest confidence is marked as a class 1 reading. These locations (except for their altitude) are used in flight modeling

discussed in subsequent sections. The noise monitor data are used as a benchmark comparison for noise results calculated by AEDT.

The framework for modeling and automation developed in this paper is independent of the data source used and will only need to be modified to account for the availability of parameters in case other data sources are used. In this work, the data used is obtained from flight operations at San Francisco International Airport (KSFO) and noise monitoring readings obtained from the SFO airport noise program (https://webtrak.emsbk.com/sfo13).

Modeling Assumptions and AEDT Capabilities

Modeling in AEDT offers users multiple settings for critical assumptions related to the modeling of performance and noise. A matrix of alternatives for these options is shown in Tables 1 and 2. While the possible options and their combinations may be large, not all listed options are compatible or included in the present work. These limitations are noted while discussing the modeling assumptions individually.

Table 1. Modeling options for departure operations.

Assumption	AEDT Default	Option 2	Option 3	Option 4	Option 5
Thrust	Full	FOQA	RT05	RT10	RT15
Weight	AEDT	FOQA	Alternate Weight		
Ground Track	Standard	FOQA			
Procedure	Standard	FOQA	NADP1_1	NADP2_11	
Weather	Standard	FOQA	ASOS	High Fidelity	
Surface	Soft	Hard			
Terrain	None	Actual			
Flaps	AEDT	FOQA			
Gear	AEDT	FOQA			
NPDs	AEDT	NPD+C			

Table 2. Modeling options for arrival operations.

Assumption	AEDT Default	Option 2	Option 3	Option 4	Option 5
Thrust	Full	FOQA			
Weight	AEDT	FOQA			
Ground Track	Standard	FOQA			
Procedure	Standard	FOQA			
Weather	Standard	FOQA	ASOS	High Fidelity	
Surface	Soft	Hard			
Terrain	None	Actual			
Flaps	AEDT	FOQA			
Gear	AEDT	FOQA			
NPDs	AEDT	NPD+C			

The SFO airport is selected for the present work because the research team has access to real-world noise monitoring data from SFO. For the purpose of this study, 52 Boeing 737-800s departing and arriving SFO have been down selected.

A number of settings are available under every assumption (row) of Tables 1 and 2, which can affect the performance and noise for each flight operation. This section aims to provide a summary of each option and an idea of how it might affect the calculations. For further details, readers are referred to the AEDT technical manual [25].

1. **Thrust Settings:** The options for thrust in AEDT can be seen through some of the procedures in the FLEET database. Apart from a full thrust assumption, the true thrust value at different points along the departure or arrival is available from the FOQA data and can be used. RT15 corresponds to a 15% reduced thrust during the takeoff procedure. Investigating thrust settings upon takeoff and cutback in ASCENT Project 45 identified 15% reduced thrust as being regularly used by operators in real-world operations. This decrease in takeoff and cutback thrust results in a 30%

decrease in area of the 80 dB SEL contour for a single-aisle aircraft [26]. Other options available within AEDT include 5% and 10% reduced thrust; however, these are not studied in the present work. The final thrust option available is the actual thrust from the flight given in the FOQA data.

2. **Procedure:** The FLEET database has two types of profiles that can be used: procedural profiles and fixed-point profiles (FPPs). Procedural profiles define an aircraft's thrust, speed, and trajectory in a series of steps. These include the standard, noise abatement departure procedure (NADP)1, and NADP2. FPPs fully define the location and state of the aircraft in the sky as well as its state: thrust and speed. FPPs are used to model FOQA data within AEDT because they can include the speed and thrust from flight data.

3. **Weight:** Modified alternate weight procedures are available within AEDT that can be combined with the standard or reduced thrust procedures. FOQA weight can also be used within AEDT while using FPPs. This way, the information regarding weight, thrust, and speed can be used in one FPP for each flight modeled.

4. **Ground Track:** The ground track is the latitude and longitude points on the ground of the aircraft during its flight. The default AEDT modeling for ground tracks are straight into the airport, parallel with whichever runway the aircraft is using upon arrival, or straight out of the airport upon departure. These default settings are likely to result in incorrect predictions when compared with real-world noise observations and are therefore not included in the current analysis. The FOQA ground track data are used in the present work, which reflects the true flight paths into or leaving airports.

5. **Weather:** The default weather settings that are used in AEDT studies are located in the AIRPORT database. These settings include temperature, relative humidity, wind speed, sea-level pressure, and dew point, which affect performance and acoustic calculations. The wind direction is always assumed to be a headwind direction. Although AEDT has the capability to utilize high-fidelity weather data in multiple formats [21], the present work is limited to the default setting.

6. **Surface and Terrain:** The surface options within AEDT are available for propeller aircraft, including hard and soft surface options that affect the ground reflection and other properties in noise calculations. For the present work, the AEDT default value is assumed for these settings.

7. **Flaps and Landing Gear:** The flap and gear schedule for modeling in AEDT are provided with each of the procedures, or the flap schedule defined in the FOQA data.

8. **Noise Power Distance (NPD) Curves:** Noise calculations in AEDT rely on NPD curves derived in a process similar to that used in aircraft noise certification. Noise levels are obtained as a function of observer distance via spherical spreading through a standard atmosphere. In a noise analysis, AEDT applies other correction factors to obtain the desired sound field metrics at the location of the receiver. NPD + configuration (NPD+C) curves that may enable more accurate noise prediction due to aircraft configuration and speed changes are under study [27] and not included in the present work.

Compatibility of Settings

Of the settings discussed previously, those that are varied in this study include the procedures and profiles, thrust, and weight. It is important to note that not all of these variations are compatible with each other. For example, the FOQA FPP are incompatible with reduced thrust or alternate weight settings because the prior specify the thrust at every step and the weight at the start of the takeoff or landing segments, while the latter two settings calculate it with respect to the standard profile. Likewise, the FOQA thrust values cannot be used in a procedural profile because they are numerical (in pounds), whereas the procedural profiles require thrust type and step type definitions that subsequently produce their own thrust values. This leads to the creation of a compatibility matrix yielding the actual number of combinations for flights to be modeled. Arrivals have fewer combinations of modeling settings. The only profiles available are standard and FPP from the FOQA data, and one thrust setting is available.

In the present study, the combination of settings yields seven different jobs per noise metric for departures. For arrival modeling, it yields two different jobs for each noise metric. Running these cases on 27 departures and 25 arrivals requires some form of automation capability discussed in detail in Reference. [20] and summarized below.

Automation Capability

An automation capability was developed to handle these combinations in a more time-efficient manner. Automation is required not only in setting up the large combinations of settings within AEDT (also called pre-AEDT automation), but also for post-processing of the results generated (post-AEDT automation). The pre-AEDT automation consists of 9 SQL automation scripts as shown in Figure 1. The user specifies the profiles to be modeled (either procedural or FPP), the ground tracks, and a combination matrix. This matrix maps Profile IDs and Ground Track IDs together with runway specifications to model the correct combinations from the matrix options in Tables 1 and 2. These scripts work on multiple AEDT and user-created databases to set up the studies. Once scripts 0a through 4b have been executed, script 5 can be executed, which gathers all of the information from the previous scripts and sets up the metric results within a new AEDT study. Once the user runs all studies within the AEDT graphical user interface, the results, including performance, emissions, and noise, are exported into csv files using a batch report run tool. Each case in the combination test matrix results in four reports, which are then processed using MATLAB and Python post-processing scripts (post-AEDT automation).

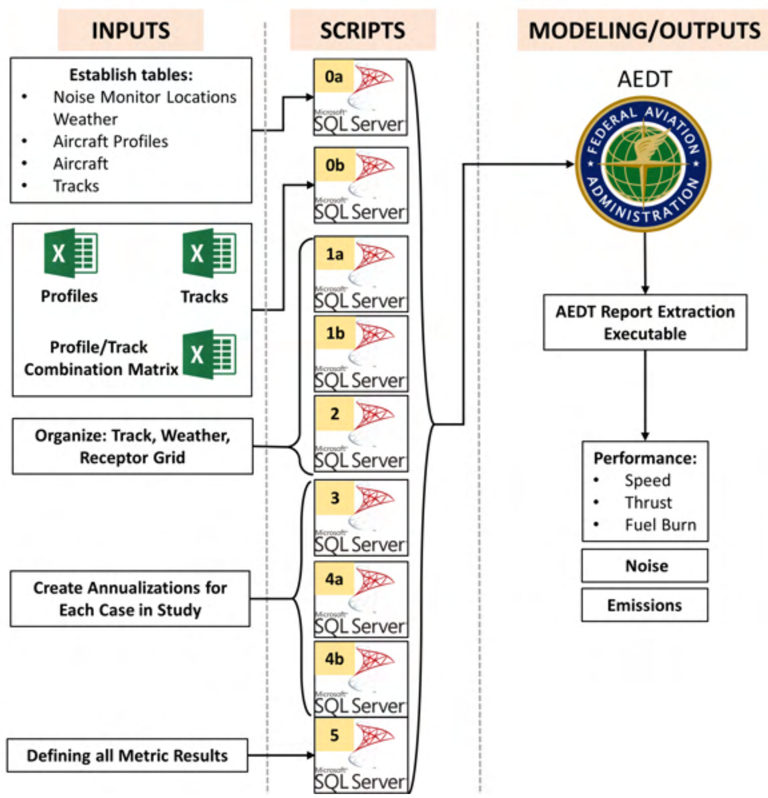

Figure 1. Noise modeling process automation steps.

Implementation of Noise Modeling Automation Framework

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The modeling framework was implemented on 27 departing and 25 arriving flights at San Francisco International Airport (KSFO) using AEDT version 3c. These flights have been given arbitrary flight IDs (GT-xxx) to anonymize the real-world flight details. Figure 2 shows a map of the noise monitor locations in the SFO airport area along with their assigned IDs. All noise monitors triggered with the highest confidence (class 1) and mapped to the corresponding flight are used as truth values for comparing AEDT predictions. In this section, detailed results are provided for one departure and one arriving flight at KSFO, followed by results on AEDT prediction accuracy on a per-noise-monitor basis.

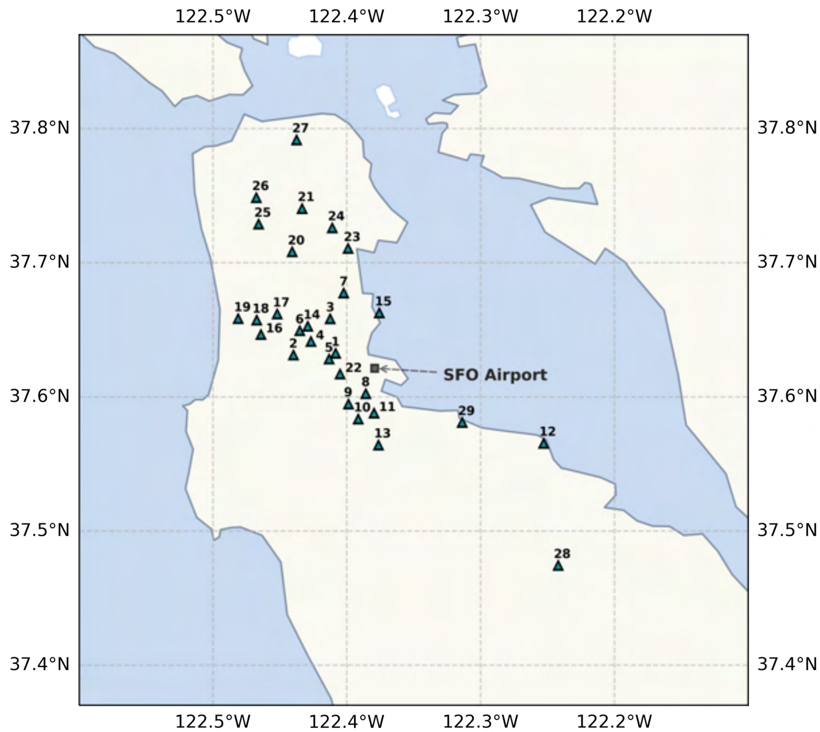

Figure 2. Location of noise monitors around San Francisco International Airport (SFO).

Although using the FOQA flight track and trajectory are expected to result in aircraft performance and noise predictions that are closest to actual, they are not necessarily always available to AEDT users. Therefore, investigating AEDT noise prediction accuracy under various modeling options is important from a usability perspective. The individual flight modeling results are elaborated in the following subsection.

Individual Flight Results

Detailed performance and noise results are available for all 52 flights, but one departure flight has been reported below as an example. Table 3 provides the AEDT airport weather parameters for the two flights of interest in the present work. AEDT airport weather uses the average annual weather and therefore is the same for both flights modeled because they operated in the same year.

Table 3. Airport weather conditions for the flights.

Weather	Temp [F]	Sea-Level Pressure [mb]	Dew Point P [F]	Relative Humidity [%]	Wind Speed [kts]	Wind Dir [°]
AEDT Default	61	1018.3	53.1	75.2	9	N/A

Flight Number: GT1015

Flight GT1015 was a Boeing 737-800 with an origin-destination pair (OD Pair) of SFO-LAX, making this a stage length 1 departure. The real-world flight data give the gross weight at takeoff as 145,591 lbs.

Figure 3 shows the performance plots for flight GT1015. This is part of the data that is extracted from AEDT using the AEDT report extraction executable. The aircraft performance using procedural profiles shows that the alternate weight reduced thrust for 15 profiles are shallower than the others, while the FOQA FPP (actual flight) is shallowest. The monitors triggered by this flight as well as the ground track can be seen in Figure 4. The noise comparison for flight GT1015 given in Figure 5 shows both underpredictions and overpredictions of the noise created at the noise monitor locations. An interesting trend is observed when the noise monitor predictions are compared to the aircraft ground track and monitor locations from Figure

3. Noise values at monitors 1, 4, 6, 18, and 19 tend to be underpredicted. They also seem to be below the aircraft flight paths. Monitors 5, 14, 16, and 17 are all further away from the flight's ground track and tend to be overpredicted. While these comparisons may not provide conclusive insights alone, they can prove valuable when aggregated across different flights and modeling assumptions.

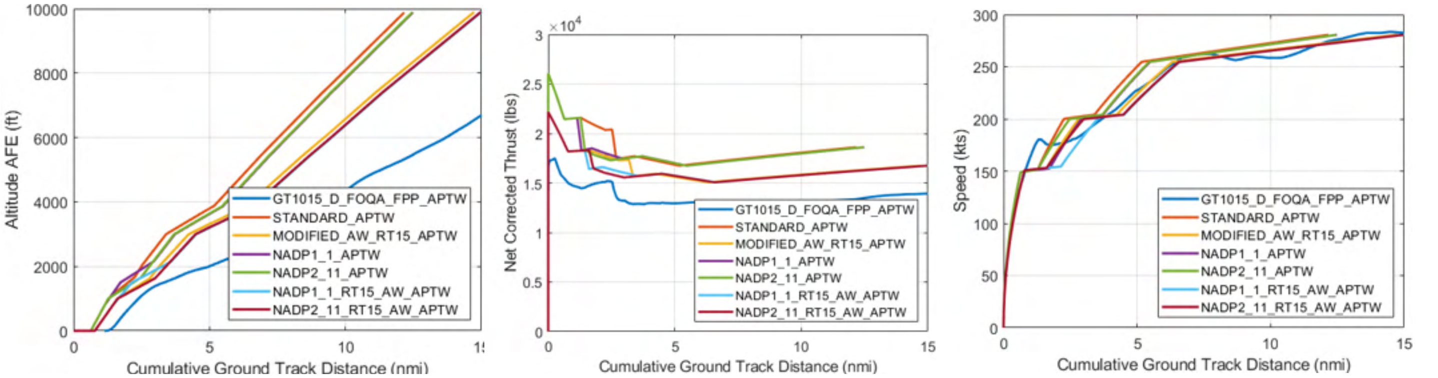

Figure 3. Altitude, thrust, and ground speed performance for flight GT1015.

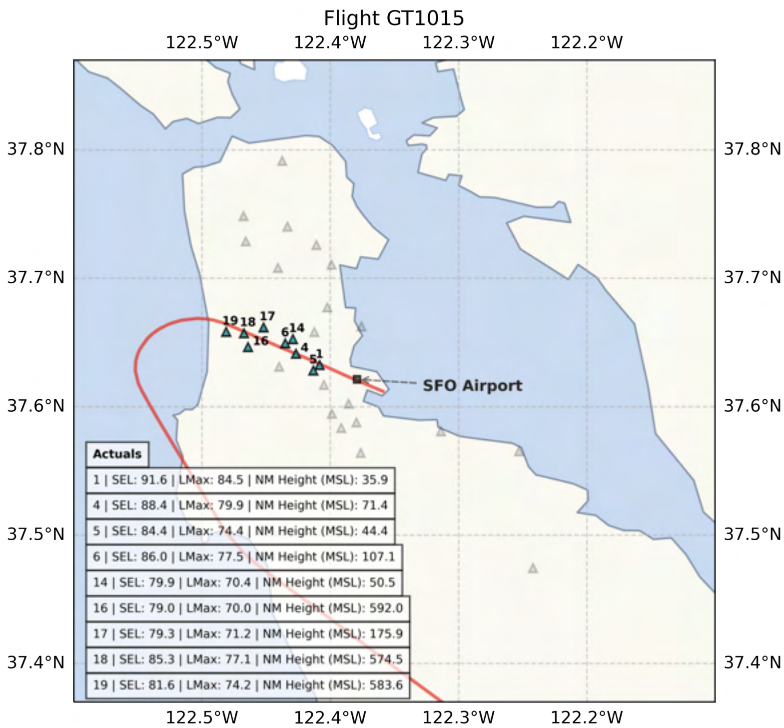

Figure 4. Trajectory and monitors triggered for flight GT1015.

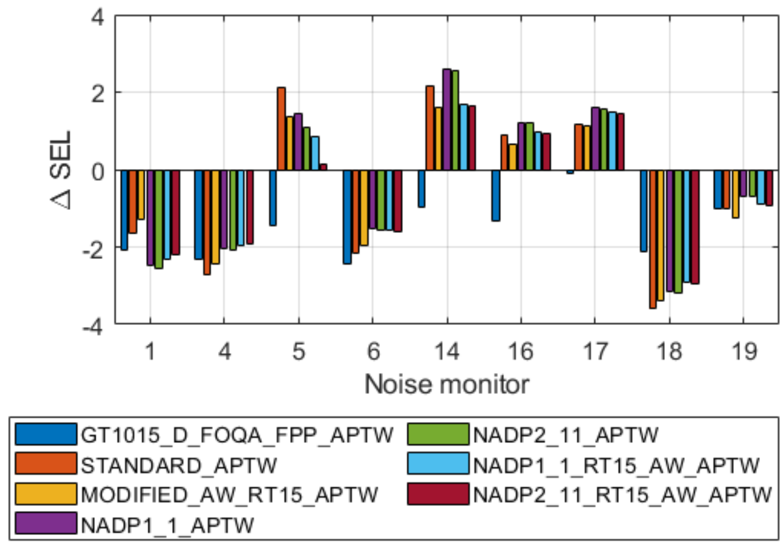

Figure 5. AEDT predicted – actual noise (dB) results for flight GT1015. SEL = sound exposure level.

Aggregate Flight Modeling Results

Individual flights can be analyzed to compare the performance and noise prediction accuracy of the different modeling options within AEDT as shown previously. To obtain more meaningful inferences, a statistical analysis of all 52 modeled flights is carried out in this section. To this end, a per-noise-monitor prediction capability was calculated using the results generated. In these, instead of viewing one flight at a time, all flights that triggered a particular noise monitor are considered. The difference between the AEDT predictions and actual noise observations for these monitors is computed and analyzed using box plots shown in Figures 6 and 7. Ideally, these box plots would show a median of zero and a small spread to show small error in predicting multiple operations compared to real-world data.

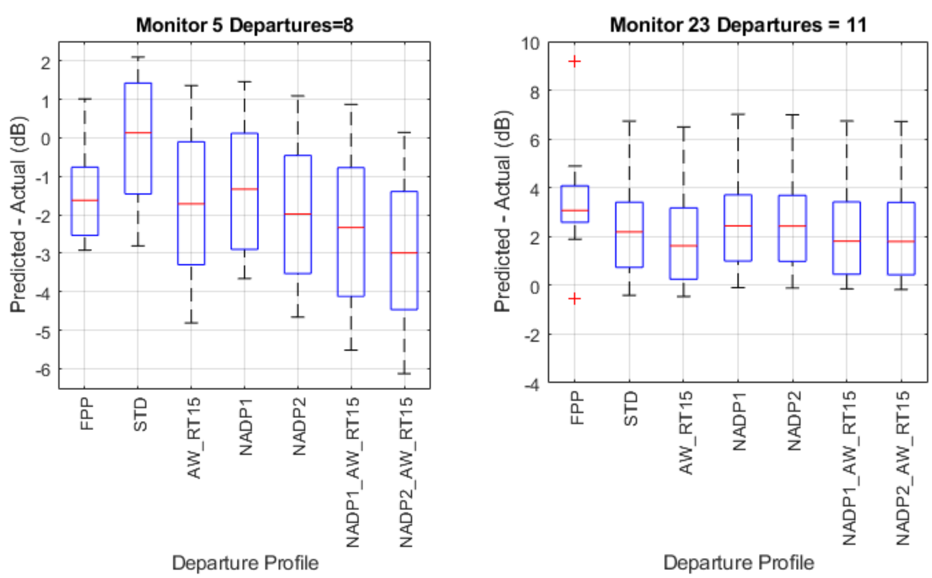

Figure 6. Predicted – actual sound exposure level (dB) noise boxplot for noise monitors 5 and 23 triggered by departing flights. FPP = fixed-point profile; STD = standard profile.

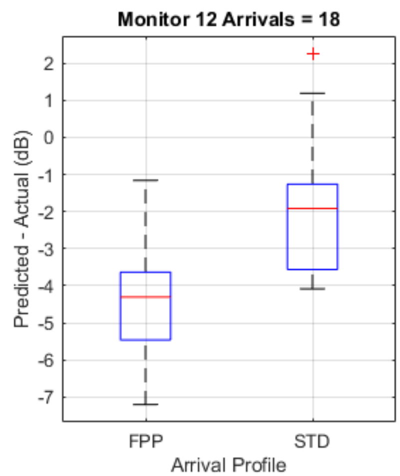

Figure 7. Predicted − actual sound exposure level (dB) noise boxplot for noise monitor 12 triggered by arriving flights. FPP = fixed-point profile; STD = standard profile.

The box plots shown in Figure 6 are generated by subtracting real-world observed SEL values from the AEDT-predicted SEL results for the 27 departures modeled. Not all flights trigger a particular monitor with class I confidence. For instance, only eight flights triggered monitor 5, whereas 11 flights triggered monitor 23. From the initial set of results of the 27 departures, it seems like the standard profile provides the best prediction accuracy for monitor 5 based on the median error being closer to 0 dB. The FOQA FPP profile provides the lowest spread between the 25% and 75% quantiles. In general, there is a trend of slight underprediction at monitor 5. For monitor 23, the overall trend seems to be slight overprediction by AEDT, with the alternate weight profiles providing results closest to actual. The FPP once again provides the lowest spread with a couple of outlier flights.

Arrivals in AEDT are modeled using just the FOQA FPPs and the standard profile. Figure 7 shows the noise results for 18 arriving flights (out of 25 modeled) that triggered monitor 12. Many of these flights flew directly over monitor 12 before touching down at SFO. Overall, AEDT modeling underpredicted the actual measurements at monitor 12, with the standard profile performing slightly better than the FOQA FPP.

The results in Figures 6 and 7 are initial and tentative results that will be updated once bulk studies of hundreds of flights have been performed within AEDT for the different modeling assumptions. They are provided here to provide a glimpse of the statistical analysis capability currently under development at Georgia Tech.

Using High-Fidelity Meteorological Data in AEDT

The Pennsylvania State University

Objective

One of the challenges in validating aircraft noise models is knowing the state of the atmosphere during field tests. In collaboration with industrial partner Spire Global (www.spire.com), the PSU team is providing relevant high-fidelity meteorological data to support the AEDT noise model validation work being conducted by Georgia Tech.

Research Approach

Spire Global has launched a fleet of low Earth orbit satellites that will provide virtual soundings of the atmosphere worldwide. Additional satellites are being launched presently, and the new meteorological data eventually will have a spatial resolution of 1 km × 1 km parallel to the ground and a vertical resolution of 500 m for every hour of the day. In contrast, the best alternative available with the same time resolution is NOAA's High Resolution Rapid Refresh (HRRR) reanalysis dataset with a 3 km × 3 km resolution, which is only available over North America [28]. In short, the GPS signals sent out by other satellites are refracted (bent) by the atmosphere, and the Spire satellites analyze the data to provide virtual soundings. This could provide a very useful resource yielding high-quality meteorological data for aviation studies.

Choice of meteorological data bundle from Spire Global

For the noise model validation work, the project team is looking at flight data and noise monitor data for KSFO. As mentioned in the 2020 annual report, the PSU team worked with Spire Global to ascertain the availability of meteorological data for the period and location of interest of the project team. The next step was to identify a meteorological data bundle from Spire Global that could be used as an input for the noise validation efforts in AEDT. At present, the publicly available version of AEDT can ingest 4-dimensional (4D; space and time) meteorological data but requires the data in a very specific structure and format. Specifically, AEDT uses geopotential heights to specify the vertical coordinate when using meteorological data. This matches the structure of the vertical grid of the data provided by the "upper-air" bundle from Spire Global; hence, this bundle was chosen for the validation work. Although the upper-air bundle contains most of the meteorological variables needed by AEDT, sea-level pressure is not included. Hence, the PSU team requested and obtained this information from Spire Global in the basic bundle, which does include the sea-level pressure data.

Preprocessing the Spire Global data before feeding it into AEDT

Although AEDT can ingest 4D meteorological data, the data first need to be converted into a structure and format that can be efficiently handled by AEDT. To achieve this, AEDT provides "weather editors" for preprocessing the meteorological data from publicly available sources. For example, AEDT can ingest data from Modern-Era Retrospective analysis for Research and Applications version 2 (MERRA-2), but the data must be preprocessed through an editor (NC4WXEditor) provided by AEDT (this is shown in the top part of Figure 8).

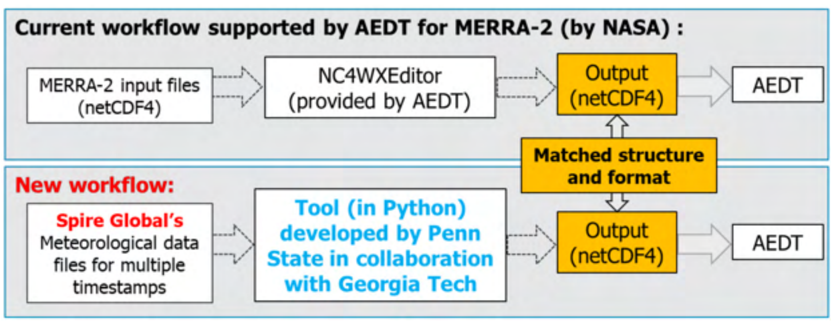

Figure 8. Using high-fidelity meteorological data in AEDT: Current and newly developed workflows. MERRA-2 = Modern-Era Retrospective analysis for Research and Applications version 2.

The Georgia Tech team previously used MERRA-2 data with AEDT and did have preprocessed versions of the MERRA-2 files (i.e., the netCDF4 output files from the weather editor). The PSU team carefully investigated these files to gain a deeper understanding of the exact format and structure of the data required by AEDT. To preprocess the meteorological files from Spire Global, PSU developed a tool written in Python (as explained in the bottom part of Figure 8). This tool combines information for multiple timestamps from the upper-air and basic bundles provided by Spire Global and converts it into a structure and format required by AEDT. The tool was tested in collaboration with Georgia Tech. The Georgia Tech team successfully ran multiple test cases in AEDT using the Spire Global meteorological data preprocessed using PSU's in-house Python code.

Working with meteorological data for a smaller geographical area and padding the data to match AEDT requirements

While attempting to match the structure and format of meteorological data as required by AEDT, the PSU team noticed that the data boundary required by AEDT spanned (at least) the whole continental US (the purple region shown in Figure 9). Spire Global noted that requesting data for the whole continental U.S. would result in a higher cost. To work around this issue, the PSU team proposed an approach of only requesting the data in the vicinity of the KSFO airport (the 100 km × 100 km area shown in red in Figure 9) and filling the rest of the grid with dummy data. The resulting meteorological data files were supplied to the Georgia Tech team. By running the same AEDT study with and without the dummy data, the Georgia Tech team confirmed that the use of dummy data did not affect the AEDT study results obtained in the vicinity of the KSFO airport.

Finally, using the data provided by Spire Global (the basic and upper-air bundles) for the area around KSFO, PSU generated meteorological files for use in AEDT (for three arrival events and three departure events). These were shared with the Georgia Tech team.

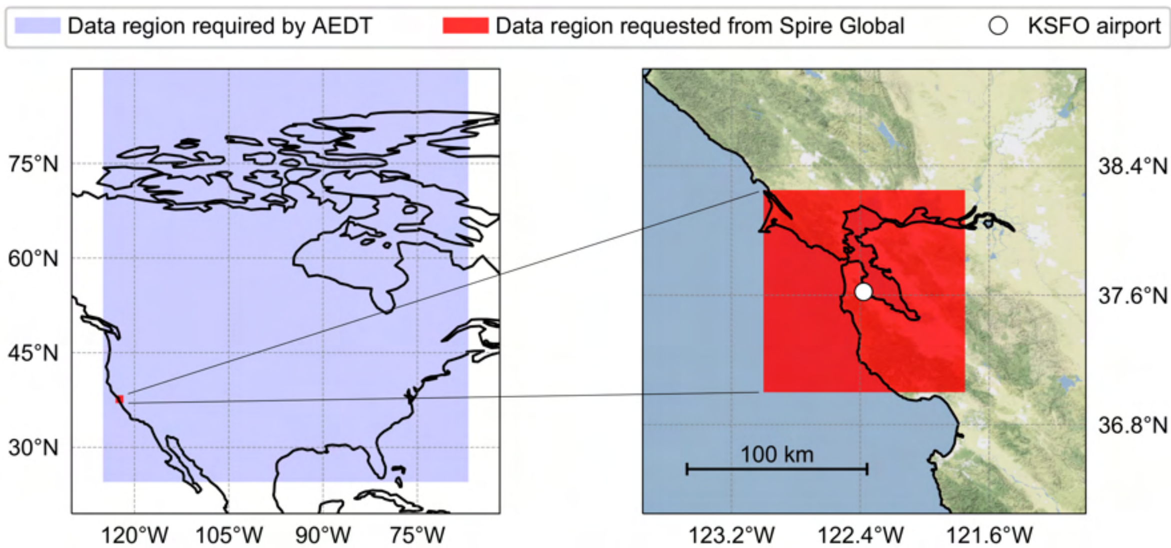

Figure 9. Maps showing (1) the region over which meteorological data is required by AEDT (shown in purple), and (2) the data region around San Francisco International Airport (KSFO) requested from Spire Global (shown in red).

Ensuring the correctness of the meteorological data and exploring alternative sources of data

To gain more confidence in the data supplied to Georgia Tech, the Penn State team compared the Spire Global data with data obtained from ERA5 (obtained from the European Centre for Medium-Range Weather Forecasts [29]). The Spire Global data and the meteorological data from ERA5 do not have the same spatial resolution; hence, a comparison was made at grid points common to both datasets. As an example, a spatial grid point closest to KSFO was chosen (latitude 37.5° N, longitude 122.5° W). The meteorological data were obtained for August 14, 2019, at 00:00 UTC. A comparison between the two datasets is shown in Figure 10. The strong agreement in temperature and humidity profiles is reassuring. The wind profiles seem to be more sensitive to the source of the meteorological data and the forecasting model used. Nevertheless, the good comparison between the data from ERA5 and Spire Global indicates that the PSU team is reading both datasets correctly and we have confidence in the meteorological data provided to Georgia Tech. This exercise also demonstrates that if Spire Global data are not available for any reason, the ERA5 data could be used as a substitute. The PSU team is also aware and capable of reading meteorological data from other publicly available sources such as HRRR [28].

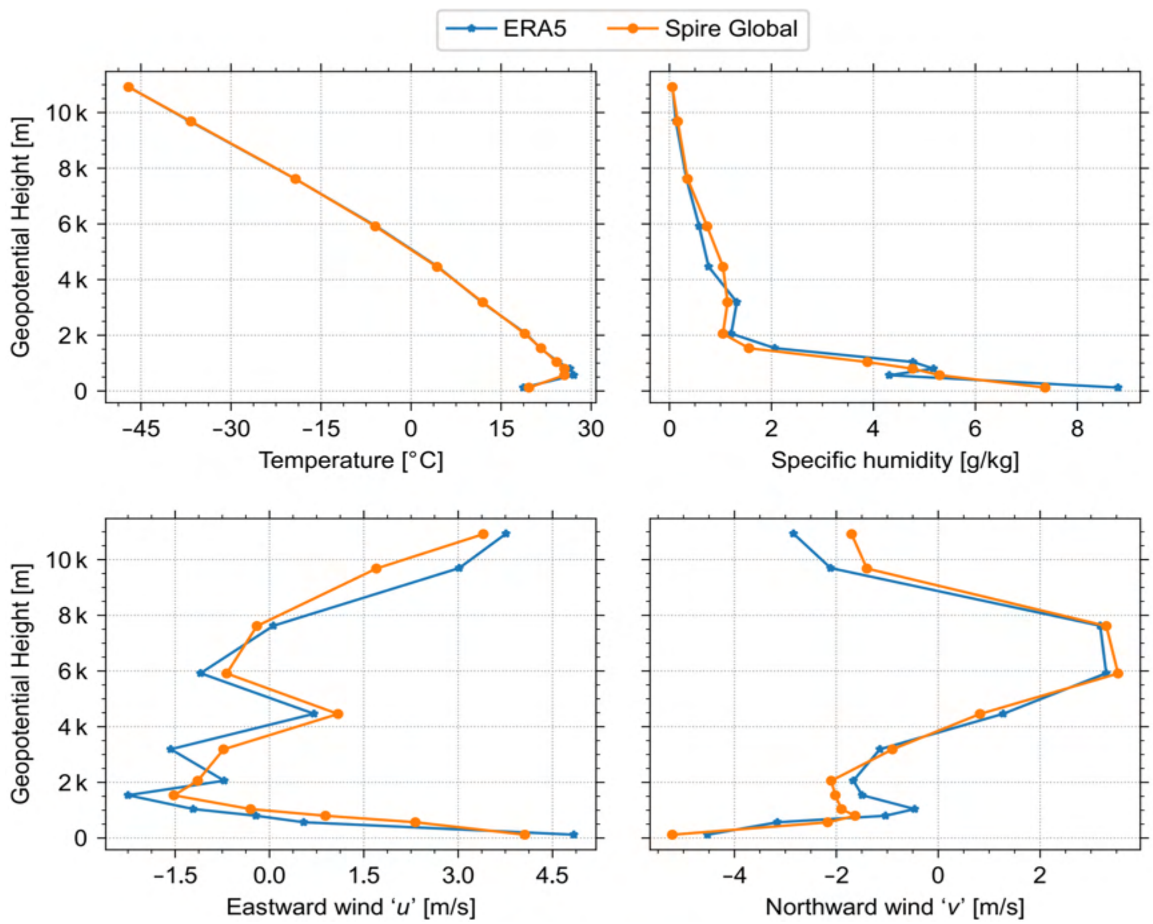

Figure 10. Comparing meteorological data from Spire Global's upper-air bundle and ERA5 (vertical grids of both data sources are not the same; hence, the figures show only the grid points common to both).

Beginning a new effort regarding AEDT's atmospheric absorption and acoustic impedance adjustments
Starting in the summer of 2021, PSU team began looking at methods to incorporate high-fidelity meteorological data into the atmospheric absorption and acoustic impedance adjustments that are used to make noise level predictions in AEDT. The PSU team has developed in-house ray tracing codes that might help improve the accuracy of AEDT noise predictions, but it is likely that incorporating those methods might slow down AEDT's noise calculation runtimes. Alternatively, using the high-fidelity meteorological data to modify the existing acoustic impedance and atmospheric absorption adjustments already utilized in AEDT might yield more accurate noise calculations while adding few additional calculations, preserving AEDT's current calculation speed.

High-fidelity meteorological data from Spire Global were accessed using Python scripts, giving the research team the ability to view data collected for multiple variables over the area surrounding the SFO airport. The data that have been collected and opened can be used to calculate multiple acoustic properties of the air, most notably the acoustic impedance and atmospheric absorption adjustments used within AEDT. Both of these properties are used in calculating noise levels. Thus far, the research team has developed maps of acoustic impedance adjustment over and around the SFO airport and are assessing the correctness and usability of those maps for possible incorporation into AEDT noise predictions.

Milestones
None.

Major Accomplishments
(Note that the project started in July 2020)
Georgia Tech accomplishments
- Completed the successful implementation of AEDT automation pipeline for (1) modeling real-world flights at various settings, and (2) extracting and visualizing results from noise modeling efforts
- Successfully ran 52 flights at all identified settings from the test matrix and ran over 300 flights with the reduced set of modeling settings
- Coordinated with PSU team to provide flight data required for tasks relevant to PSU tasks

PSU accomplishments
- Successfully wrote a tool in Python to convert Spire Global data into a structure and format usable by AEDT
- Obtained high-fidelity meteorological data from Spire Global, processed the data, and provided it to Georgia Tech for three departure and three arrival events
- Demonstrated the ability to obtain meteorological data from alternative sources
- Initiated a study on high-fidelity meteorological data affecting AEDT's atmospheric absorption and acoustic impedance adjustments

Publications
None

Outreach Efforts
Held biweekly calls with the FAA, Volpe, and ATAC, and participated in biennial ASCENT meetings.

Awards
None

Student Involvement
Georgia Institute of Technology
Graduate research assistants: Ana Gabrielian, Emily Lembcke, Vinh Bui, Sabastian Abelezele, Amber Willitt.
Undergraduate student: Jennifer Nolan

The Pennsylvania State University
Graduate research assistants: Harshal Patankar, Emma Shaw.

Plans for Next Period
The primary focus for the next period will be on the following:
- GT will continue to model the remaining flights that have been matched with corresponding noise monitor data at all the identified settings in AEDT.
- GT will provide insights into statistical significance of results at various noise monitoring stations.
- GT will build an interactive dashboard that contains the modeling results with all different settings combined for performing trade-off studies.
- PSU plans to continue supporting the Georgia Tech team, considering the differences in AEDT noise predictions with and without high-fidelity weather and assessing whether updating the atmospheric absorption and acoustic impedance adjustments with high-fidelity weather has a noticeable effect on AEDT noise predictions.

References
[1] Juniac, A. d., "IATA Annual Review 2018," retrieved July 4, 2019, [Online]. Available: https://www.iata.org/publications/Documents/iata-annual-review-2018.pdf, 2018.Suder, K., "Overview of the NASA Environmentally Responsible Aviation Project's propulsion technology portfolio,"48thAIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, 2012, p. 4038.

[3] Lim, D., Behere, A., Jin, Y.-C., Li, Y., Kirby, M., Gao, Z., and Mavris, D. N., "Improved Noise Abatement Departure Procedure Modeling for Aviation Environmental Impact Assessment," AIAA Scitech 2020 Forum, 2020. doi:10.2514/6.2020-1730.
[4] Behere, A., Lim, D., Li, Y., Jin, Y.-C., Gao, Z., Kirby, M., and Mavris, D. N., "Sensitivity Analysis of Airport level Environmental Impacts to Aircraft thrust, weight, and departure procedures," AIAA Scitech 2020 Forum, 2020. doi:10.2514/6.2020-1731.
[5] Behere, A., Isakson, L., Puranik, T., Li, Y., Kirby, M., and Mavris, D. N., "Aircraft Landing and Takeoff Operations Clustering for Efficient Environmental Impact Assessment," AIAA Aviation 2020 Forum, 2020. doi:10.2514/6.2020-2583.
[6] LeVine, M. J., Lim, D., Li, Y., Kirby, M., and Mavris, D. N., "Quantification of Error for Rapid Fleet-Level Noise Computation Model Assumptions," Journal of Aircraft, Vol. 56, No. 4, 2019, pp. 1689–1696. doi:10.2514/1.C035169.
[7] Monteiro, D. J., Prem, S., Kirby, M., and Mavris, D. N., "React: A Rapid Environmental Impact on Airport Community Tradeoff Environment,"2018 AIAA Aerospace Sciences Meeting, 2018. doi:10.2514/6.2018-0263.
[8] LeVine, M. J., Bernardo, J. E., Pfaender, H., Kirby, M., and Mavris, D. N., "Demonstration of a Framework for Comparing Aviation Environmental Impact Mitigation Strategies," Journal of Aircraft, Vol. 56, No. 3, 2019, pp. 1116–1125. doi:10.2514/1.C035170.
[9] Yu, A., and Hansman, R., "Approach for Representing the Aircraft Noise Impacts of Concentrated Flight Tracks," AIAA Aviation2019 Forum, 2019. doi:10.2514/6.2019-3186.
[10] Salgueiro, S., Thomas, J., Li, C., and Hansman, R. J., "Operational Noise Abatement through Control of Climb Profile on Departure," AIAA Scitech 2021 Forum, 2021. doi:10.2514/6.2021-0007.
[11] Thomas, J. L., and Hansman, R. J., "Framework for Analyzing Aircraft Community Noise Impacts of Advanced Operational Flight Procedures," Journal of Aircraft, Vol. 56, No. 4, 2019, pp. 1407–1417.
[12] Behere, A., Rajaram, D., Puranik, T. G., Kirby, M., and Mavris, D. N., "Reduced Order Modeling Methods for Aviation Noise Estimation," Sustainability, Vol. 13, No. 3, 2021. doi:10.3390/su13031120.
[13] Behere, A., Bhanpato, J., Puranik, T. G., Kirby, M., and Mavris, D. N., "Data-driven Approach to Environmental Impact Assessment of Real-World Operations," AIAA Scitech 2021 Forum, 2021. doi:10.2514/6.2021-0008.
[14] Page, J. A., Hobbs, C. M., Plotkin, K. J., and Stusnick, E., "Validation of aircraft noise prediction models at low levels of exposure," Report NASA/CR-2000-210112, NASA, April 2000. Retrieved 27 Oct 2021, [Online]. Available: https://ntrs.nasa.gov/api/citations/20000068518/downloads/20000068518.pdf
[15] Forsyth, D. W., and Follet, J. I., "Improved Airport Noise Modeling for High Altitudes and Flexible Flight Operations," 2006.
[16] Plotkin, K. J., Page, J. A., Gurovich, Y., Hobbs, C. M., et al., "Detailed weather and terrain analysis for aircraft noise modeling," Tech. rep., John A. Volpe National Transportation Systems Center (US), 2013
[17] Hobbs, C. M., Gurovich, Y. A., Boeker, E., Hasting, A., Rapoza, A., Page, J., and Senzig, D., "Improving AEDT Noise Modeling of Mixed Ground Surfaces," Tech. rep., 2017
[18] Downing, J. M., Calton, M. F., Page, J. A., and Rochat, J. L., "Improving AEDT Modeling for Aircraft Noise Reflection and Diffraction from Terrain and Manmade Structures," Tech. Rep. ACRP 02-79, TRB, 2019.
[19] Hastings, A. L., "Traffic Noise Model 3.0 - Technical Manual," Tech. Rep. FHWA-HEP-20-012, U.S. Department of Transportation, Volpe National Transportation Systems Center, Cambridge, MA, December 2019
[20] Gabrielian, A. B., Puranik, T. G., Bendarkar, M. V., Kirby, M., Mavris, D., and Monteiro, D., "Noise Model Validation using Real World Operations Data,"AIAA AVIATION Forum, 2021. doi:10.2514/6.2021-2136.
[21] Gabrielian, A., Puranik, T., Bendarkar, M., Kirby, M., and Mavris, D., "Validation of the aviation environmental design tool's noise model using high fidelity weather," 2021, pp. 4810–4822. doi:10.3397/IN-2021-2846.
[22] "Advisory Circular, 120-82 - Flight Operational Quality Assurance," , April 2004. Url: https://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/23227
[23] Puranik, T. G., and Mavris, D. N., "Anomaly Detection in General-Aviation Operations Using Energy Metrics and Flight-Data Records," Journal of Aerospace Information Systems, Vol. 15, No. 1, 2018, pp. 22–35. doi:10.2514/1.I010582.
[24] Lee, H., Madar, S., Sairam, S., Puranik, T. G., Payan, A. P., Kirby, M., Pinon, O. J., and Mavris, D. N., "Critical Parameter Identification for Safety Events in Commercial Aviation Using Machine Learning," Aerospace, Vol. 7(6), 2020, p. 73.doi:10.3390/aerospace7060073.
[25] Ahearn, M., Boeker, E., Gorshkov, S., Hansen, A., Hwang, S., Koopmann, J., Malwitz, A., Noel, G., Reherman, C. N., Senzig,D. A., et al., Aviation Environmental Design Tool (AEDT) Technical Manual Version 2c, FAA, 2016.
[26] Mavris, D., Kirby, M., Lim, D., Li, Y., Pfaender, H., Levine, M., Brooks, J., Behere, A., Gao, Z., Chan Jin, Y., and Kim, J. "Project 045 Takeoff/Climb Analysis to Support AEDT APM Development," Tech. Rep. ACRP 02-79, ASCENT, 2018.

[27] Mavris, D., "Project 043 Noise Power Distance Re-Evaluation," 2019. URL: https://s3.wp.wsu.edu/uploads/sites/2479/2020/05/ASCENT-Project-043-2019-Annual-Report.pdf, last accessed 14 June 2020.

[28] Horel, J., and B. Blaylock. "Archive of the High-Resolution Rapid Refresh model." *University of Utah: Salt Lake City, UT, USA* (2015).

[29] Copernicus Climate Change Service (C3S) (2017): ERA5: Fifth generation of ECMWF atmospheric reanalyses of the global climate. Copernicus Climate Change Service Climate Data Store (CDS), *Accessed in February/March 2020*. https://cds.climate.copernicus.eu/cdsapp#!/home