Project 062 Noise Model Validation for AEDT

Georgia Institute of Technology
The Pennsylvania State University

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    1. Noise Modeling in AEDT with Automation
    2. Assessing the Use of High-Fidelity Meteorological Data in AEDT Noise Calculations

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Project Funding Level

The project is funded by the FAA at the following levels: Georgia Tech: $235,000; PSU: $140,000. Cost-sharing details are below.

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, as well as 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.

For PSU, Spire Global (http://www.spire.com/), is providing cost-sharing funds in the form of meteorological data and research support. The point of contact for this cost sharing is Ms. Ashley O'Neil (703-853-8468; ashley.oneill@spire.com). Metropolitan Washington Airports Authority is providing sound level meter data from Dulles International Airport as in-kind cost sharing; the point of contact is Mr. Mike Jeck (703-417-1204; Michael.jeck@mwaa.com). Additional in-kind cost sharing is being provided by the PSU College of Engineering to meet the required matching of $140,000.

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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 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 several validation and verification efforts in the past, specifically at the Denver International Airport (DIA), and has shown continual improvements in the agreement between modeling predictions and measurement data. During the development of AEDT, multiple algorithm updates have occurred. This project seeks to quantify the new noise modeling capabilities through comparison with 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 regarding 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 PSU on the assessment of the noise propagation assumptions and the use of higher-fidelity weather data.

Task 1 – Noise Modeling in AEDT with Automation

Georgia Institute of Technology

Background and Objective

In the past decade, demand for air passenger services growth has increased, with a long-term average exceeding 5% in terms of revenue passenger miles (Juniac, 2012). To mitigate the environmental impacts of this growth in aviation, and to maximize the economic benefits that can be achieved through higher efficiency and performance, NASA's Environmentally Responsible Aviation project has suggested aggressive goals (Suder, 2012). This set of goals includes 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 (Federal Aviation Administration, n.d.) has among of the most advanced capabilities for both modeling aircraft operations and computing 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 in airports, airspace, and other applicable aviation activities.

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 to mitigate community noise either closer to the airport or further afield. Lim, et al. (2020) have provided a set of 20 NADP profiles suitable for modeling a large variety of operations that are typically observed in the real world. Behere & Lim (2020) and Behere & Isakson (2020) have focused on quantifying the impacts of such NADP profiles on noise modeling and have identified the most representative NADP profiles. AEDT has also been used in the creation of alternative rapid noise modeling tools (Levine, 2019; Monteiro, 2018), in comparing aviation environmental impact mitigation strategies (Yu, 2019), and in various other community noise quantification studies (Yu, 2019; Salgueiro, 2021; Thomas, 2019). Other efforts have focused on using large amounts of real-world data to produce reduced-order models for rapid computation of noise impacts (Behere & Rajaram, 2021) or for estimating the impacts of average types of operations at different airports (Behere & Bhanpato, 2021).

Prior studies related to noise model validation date back to AEDT's predecessor, INM. Several prior efforts have focused on validating AEDT or INM to quantify the agreement between the model predictions and the data recorded from actual operations. Page et al. (2000) have investigated a 1997 data set from DEN to determine how INM's prediction accuracy changed with different thrust prediction methods. They have found that the 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. Forsyth and Follet (2006) used the same 1997 DEN data to update INM's database, with an emphasis on higher altitudes. Spectral classes were created to correct the NPD information with respect to SAE AIR-1845 atmospheric absorption. In another study performed with the 1997 DEN data, Plotkin et al. (2013) studied options to further enhance the modeling capability by accounting for the effects of weather and terrain.

Since its introduction by the FAA in 2015, numerous studies have been performed on AEDT. Hobbs et al. (2017) have proposed an easily implementable method for including ground cover effects on noise propagation calculations by using algorithms originally implemented in the Advanced Acoustic Model (Page, 2000). These algorithms use optical straight-ray theory, as adapted for acoustics, to model noise propagation, in addition to the Fresnel ellipse method. This process has been found to improve noise propagation calculations with respect to empirical data, on data from Portland International Airport, San Francisco International Airport (SFO), and Oakland International Airport. 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: the Traffic Noise Model (TNM) (Hastings, 2019), 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, the TNM method was recommended as the best option, because its noise calculations have variability and consistency similar to those of AEDT's baseline calculations. In previous research by Gabrielian et al. (2021), an automated framework was demonstrated for validation of noise modeling capabilities within AEDT by using real-world flight and noise monitor data. In other work, the authors studied AEDT's noise prediction capability while using high-fidelity weather data (Gabrielian & Puranik, 2021).

The remainder 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 particular or aggregate insights.

Research Approach

System-level noise modeling in this report follows the procedure detailed in our previous work (Gabrielian & Puranik, 2021). Two important elements in this modeling are summarized herein for completeness: (a) the data sources used during modeling, and (b) the modeling assumptions and alternatives available for each assumption.

Data Sources Used

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

1. ***Flight operational quality assurance (FOQA)*** data are recorded by the airline operating the flight. The basis for the FOQA program is laid out in 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" (FAA, 2004). Therefore, FOQA systems record large amounts of data at one recording per second (i.e., 1 Hz). These data have been used for several safety-related applications in prior work (Puranik, 2018; Lee, 2020). The important elements of the FOQA data in this manuscript relate to the detailed time history of parameters such as altitude, speed, thrust, weight, configuration (flaps and gear), and so on, for each flight modeled in AEDT.
2. ***Noise monitoring data*** contain 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 manuscript is independent of the data source used and will need to be modified only to account for the availability of parameters if other data sources are used. In this work, the data used are obtained from flight operations at SFO and noise monitoring readings obtained from the SFO airport noise program (SFO, n.d.).

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. Although 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	Alternative 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			

SFO is selected for the present work because the research team has access to real-world noise monitoring data from that airport. For the purposes of this study, 269 departing and arriving flights at SFO have been down selected. The flights consist of Boeing 717-200; 737-800,900; 757-200,300; Airbus A319-100 and A320-200 airframes.

Several settings are available under every assumption (row) in Tables 1 and 2, which can affect the performance and noise for each flight operation. This section provides a summary of each option and how it might potentially affect the calculations. For further details, readers are referred to the AEDT technical manual (Ahearn, 2016).

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.

Investigation of thrust settings upon takeoff and cutback in ASCENT Project 45 has identified that 15% reduced thrust is regularly used by operators in real-world scenarios. This decrease in takeoff and cutback thrust results in a 30% decrease in the area of the 80-dB SEL contour for a single-aisle aircraft (Mavris, 2018). Other options available within AEDT include 5% and 10% reduced thrust; however, these options 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. Examples of procedural profiles include the standard profile, NADP1, 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 alternative 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 with FPPs. In 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 comprises the latitude and longitude points on the ground of the aircraft during its flight. The default AEDT modeling for ground tracks is straight into the airport, parallel with the runway that the aircraft is using upon arrival, or straight out of the airport upon departure. These default settings are likely to result in incorrect predictions in comparison with real-world noise observations and are therefore not included in the current analysis. The FOQA ground track data, reflecting the true flight paths into or leaving airports, are used in the present work.

5. ***Weather:*** The default weather settings 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 can use 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. ***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 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 (Mavris, 2019) and are not included in the present work.

Compatibility of Settings

Of the settings discussed previously, those varied in this study include the procedures and profiles, thrust, and weight. Importantly, not all these variations are compatible with one another. For example, the FOQA FPPs are incompatible with reduced thrust or alternative weight settings, because the FOQA FPPs specify the thrust at every step, and the weight at the start of the takeoff or landing segments, whereas the reduced thrust or alternative weight settings calculate these parameters 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. Consequently, a compatibility matrix is created, yielding the actual number of combinations for flights to be modeled. Arrivals have fewer combinations of modeling settings than departure profiles. The only profiles available for arrivals are the 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 129 departures and 140 arrivals requires some form of automation capability, as discussed in detail in reference (Gabrielian & Puranik, 2021a) and summarized below.

Automation Capability

An automation capability was developed to handle these combinations in a time-efficient manner. Automation is required not only for setting up the many 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 nine SQL automation scripts (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 Table 1 and Table 2. These scripts work on multiple AEDT and user-created databases to set up the studies. After scripts 0a through 4b have been executed, script 5 can be executed, which gathers all the information from the previous scripts and sets up the metric results within a new AEDT study. After the user runs all studies within the AEDT graphical user interface, the results, including performance, emissions, and noise, are exported into .csv files with a batch report run tool. Each case in the combination test matrix results in four reports, which are then processed with MATLAB and Python post-processing scripts (post-AEDT automation).

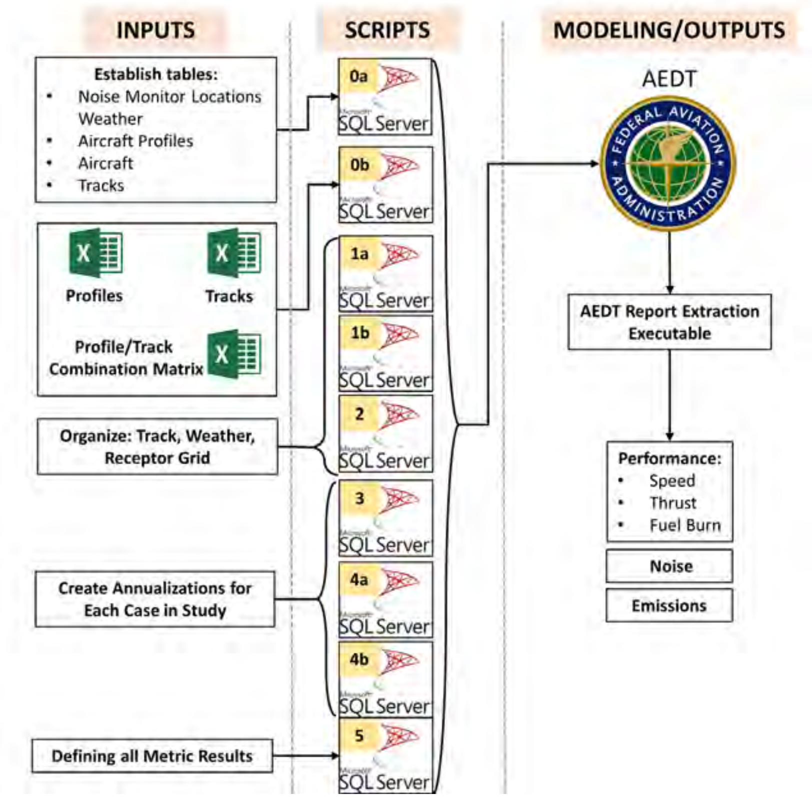


Figure 1. Noise modeling process automation steps.

Preliminary Results

The modeling framework was implemented on 129 departing and 140 arriving flights at SFO by using AEDT version 3c. In total, there are 616 (437 departures and 179 arrivals) noise events, wherein a noise event refers to a particular flight triggering a particular monitor. The number of noise events is greater than the number of flights because some flights triggered multiple monitors. The 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 SFO, followed by results on AEDT prediction accuracy on a per-noise-monitor basis.

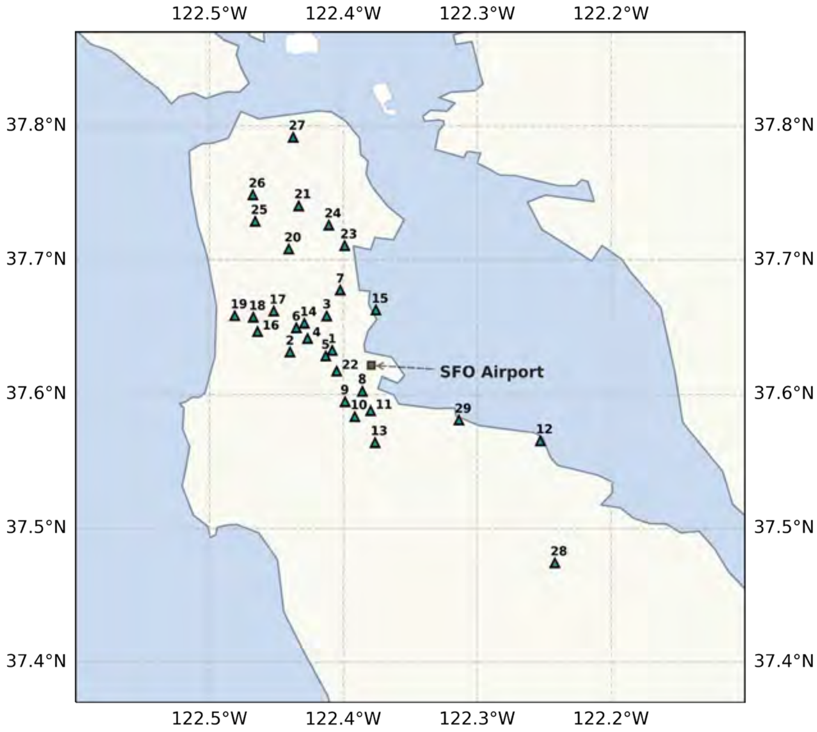


Figure 2. Locations of noise monitors around San Francisco International Airport (SFO).

Although using the FOQA flight track and trajectory are expected to result in aircraft performance and noise predictions that are closest to those measured, 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 upon in the following subsection.

Individual Flight Results

Detailed performance and noise results are available for all 269 flights, but one departure flight is 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	Temperature (°F)	Sea-level pressure (mb)	Dew point P (f)	Relative humidity (%)	Wind speed (kts)	Wind direction (°)
AEDT default	57.88	1,016.65	48.13	69.92	8.76	N/A

Flight Number GT1015

Flight GT1015 was a Boeing 737-800 with an origin–destination pair of SFO–LAX, thus 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, as part of the data extracted from AEDT with the AEDT report extraction executable. The aircraft performance, on the basis of procedural profiles, shows that the alternative weight reduced thrust values for 15 profiles are shallower than the others, whereas the FOQA FPP (actual flight) is shallowest. The monitors triggered by this flight as well as the ground track are shown in Figure 4. The noise comparison for flight GT1015 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 with 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 appear to be below the aircraft flight paths. Monitors 5, 14, 16, and 17 are all further from the flight's ground track and tend to be overpredicted. Although these comparisons may not provide conclusive insights alone, they can be valuable when aggregated across different flights and modeling assumptions.

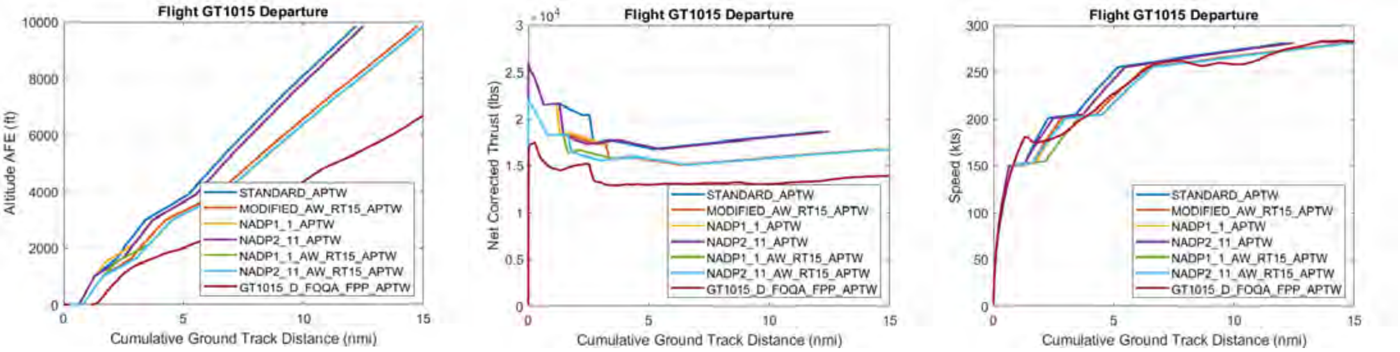
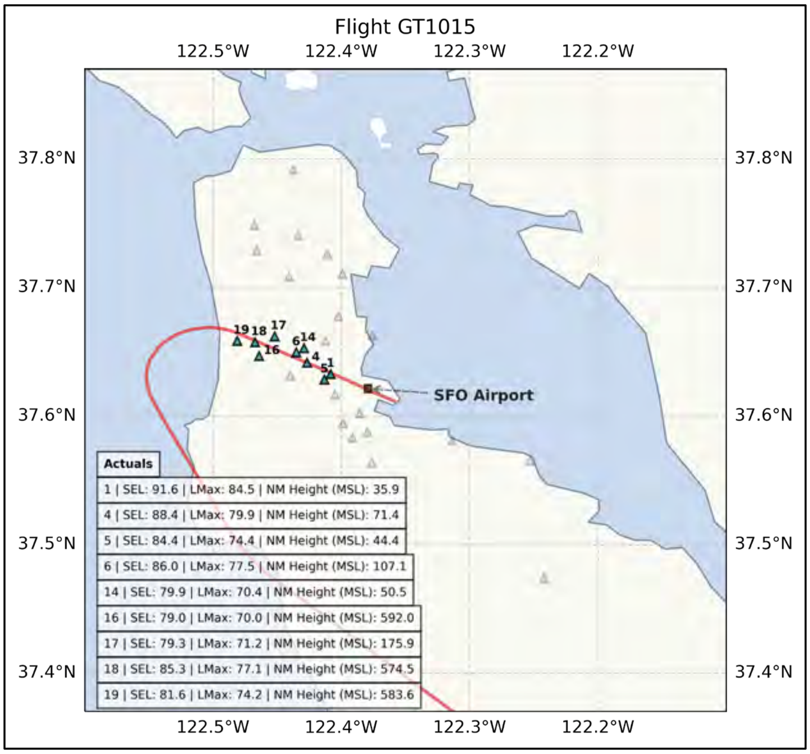


Figure 3. Altitude, thrust, and ground speed performance for flight GT1015.



Actuals

1 | SEL: 91.6 | LMax: 84.5 | NM Height (MSL): 35.9
4 | SEL: 88.4 | LMax: 79.9 | NM Height (MSL): 71.4
5 | SEL: 84.4 | LMax: 74.4 | NM Height (MSL): 44.4
6 | SEL: 86.0 | LMax: 77.5 | NM Height (MSL): 107.1
14 | SEL: 79.9 | LMax: 70.4 | NM Height (MSL): 50.5
16 | SEL: 79.0 | LMax: 70.0 | NM Height (MSL): 592.0
17 | SEL: 79.3 | LMax: 71.2 | NM Height (MSL): 175.9
18 | SEL: 85.3 | LMax: 77.1 | NM Height (MSL): 574.5
19 | SEL: 81.6 | LMax: 74.2 | NM Height (MSL): 583.6

Figure 4. Trajectory and monitors triggered for flight GT1015.

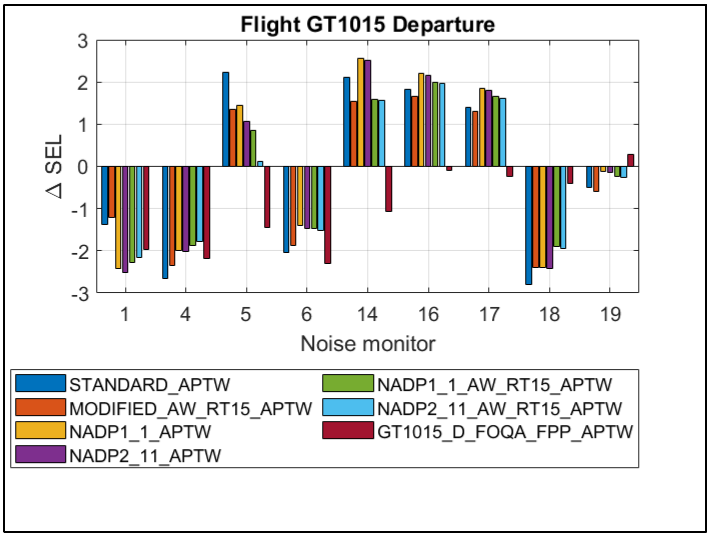


Figure 5. AEDT predicted − measured noise (dB) results for flight GT1015. SEL, sound exposure level.

Identifying Outliers

According to the results of the bulk analysis, some flights had relatively high Δ SEL (AEDT predicted − measured noise) values. Some flights with these high Δ SEL values were investigated to identify any anomalous patterns or factors. The identified anomalous patterns or factors causing the high Δ SEL can be used to easily rule out flights in future analyses, to prevent the simulation of anomalous flights whose results will eventually be discarded.

On the basis of preliminary observation of the data, several anomalous factors were identified. Results from flights that triggered monitor 8 consistently had high Δ SEL. This monitor has therefore been excluded from all further analyses and results. Some monitors had duplicate or multiple readings for the same flight for the same noise event. The Δ SEL could be high in these cases depending on the reading chosen. Therefore, the reading from the noise monitor corresponding to the point of closest slant distance for the flight that triggered it was selected. From some departure flights' tracks, we observed that some monitors located far behind the takeoff point and in the opposite direction of the flight path were triggered. Finally, some arrival flights had tracks that looped around the monitors. Some of these were arrivals that had to go-around to attempt landing a second time. After elimination of flights affected by the aforementioned anomalous factors, some flights with high Δ SEL still remained. Further analyses were conducted for these additional flights, and the SEL value measured by the noise monitor was assumed to be from a non-flight related event that could have occurred near the monitor. As stated earlier, a total of 616 noise events (437 departures and 179 arrivals) were present; after exclusion of flights affected by anomalous factors, 488 events remained (368 departures and 120 arrivals). The 269 modeled flights also reduced to 211 (97 departures and 114 arrivals).

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, we perform a statistical analysis of all 211 modeled flights in this section. To this end, a per-noise-monitor prediction capability was calculated by using the results generated for only departure flights. Instead of viewing one flight at a time, all flights that triggered a particular noise monitor are considered at each profile. The eight profiles for the departures are Alternate Weight Reduced Thrust (AW_RT15), Flight Operations Quality Assurance Fixed Point Profile (FOQA_FPP), Noise Abatement Departure Procedure Alternate Weight Reduced Thrust (NADP1_AW_RT_15), Noise Abatement Departure Procedure Alternate Weight Reduced Thrust (NADP2_AW_RT_15), NADP1, NADP2, Standard Procedure with Average Airport Weather (STD_APTW), and Standard Procedure with Automated Surface Observing System (ASOS) Airport Weather (STD_ASOS). The difference between the AEDT predictions and measured noise observations for these monitors is computed and analyzed with box plots (Figures 6–8). Ideally, these box plots would show a median of zero and a small spread, indicating minimal error between predictions of multiple operations and real-world data.

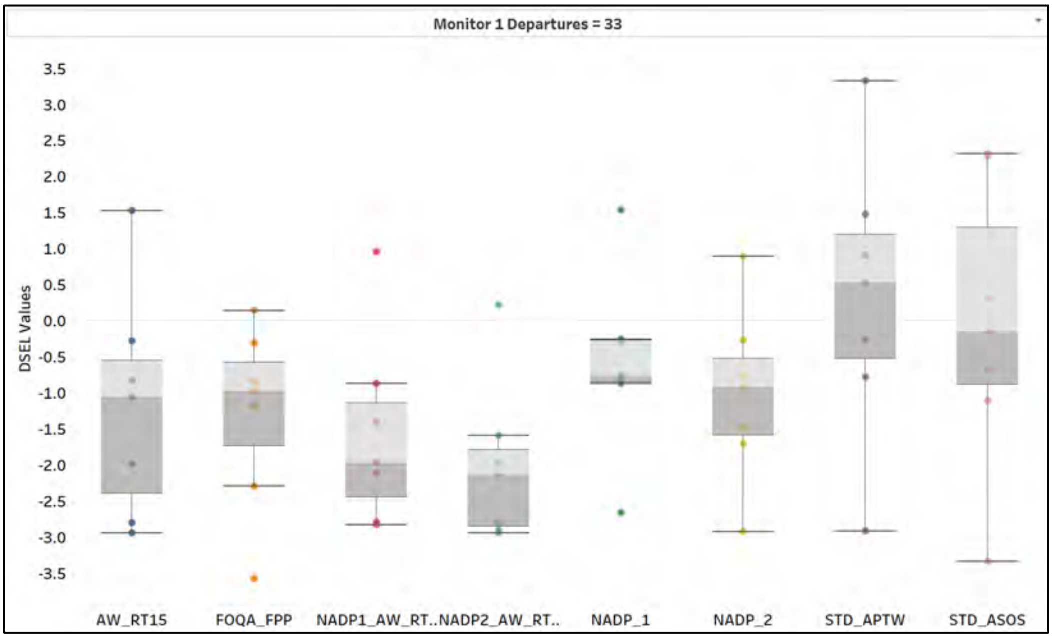


Figure 6. Predicted – measured sound exposure level (dB) noise box plot for noise monitor 1 triggered by departing flights.

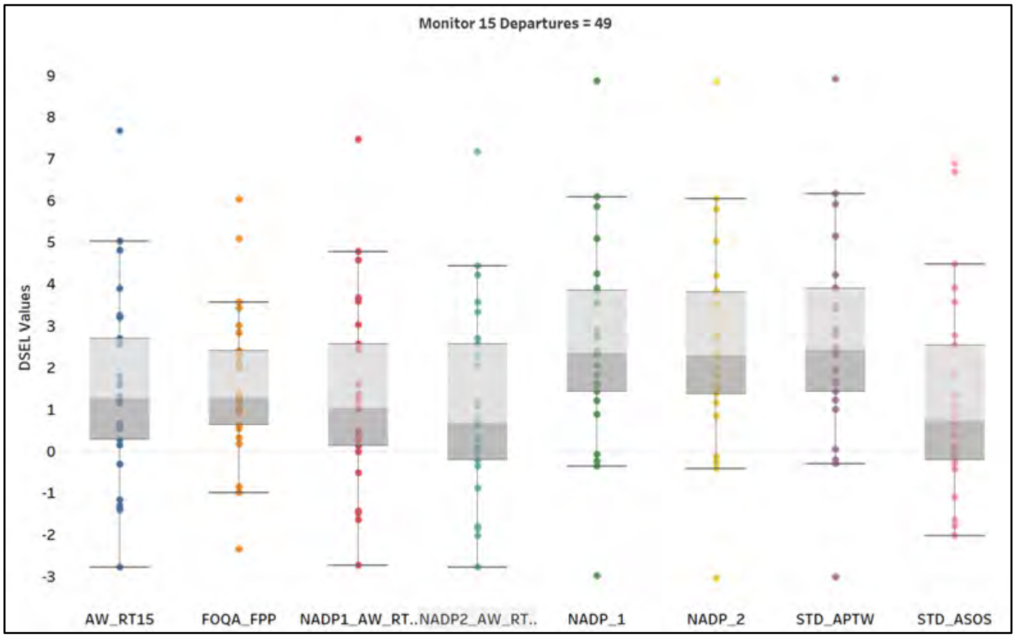


Figure 7. Predicted – measured sound exposure level (dB) noise box plot for noise monitor 15 triggered by departing flights

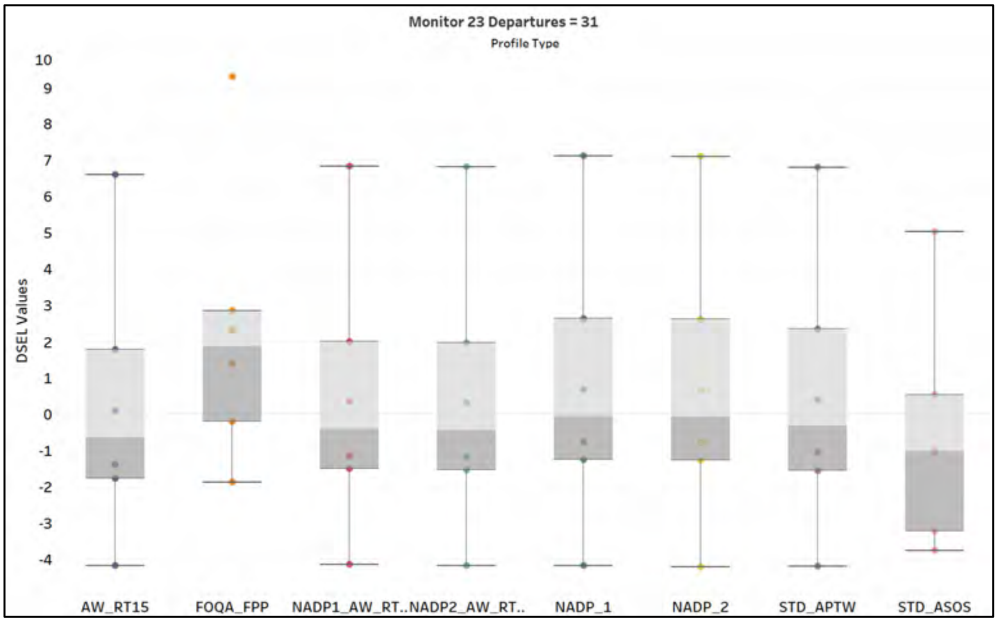


Figure 8. Predicted − measured sound exposure level (dB) noise box plot for noise monitor 23 triggered by departing flights.

The box plots shown in Figures 6–8 are generated by subtracting real-world measured SEL values from the AEDT-predicted SEL results for the 97 departures. Not all flights triggered a particular monitor with class I confidence. For instance, only 33 flights triggered monitor 1, whereas 49 flights triggered monitor 15. According to an initial analysis of all 97 departures, the FOQA_FPP profile provides the best prediction precision for all 25 monitors in the filtered data set, according to the minimal spread in the Δ SEL values and low median error. The STD_APTW and NADP profiles provide median errors closer to zero than the FOQA predictions. However, they also have some of the highest spreads between the 25% and 75% quantiles. Consequently, these three profiles perform well in predicting the average sound level over many operations but may have large errors for individual flight noise predictions. In general, a trend of slight underprediction at all monitors is seen for all profiles. However, for monitor 15, the overall trend appears to be overprediction by AEDT, and the alternative weight profiles provide results closest to the measured values. The FOQA_FPP profile again provides the lowest spread with a few outlier flights.

The box plots in Figures 6–8 are preliminary results that will be updated after bulk studies of hundreds of flights have been performed within AEDT for the different modeling assumptions. As shown, numerous outliers (|Δ SEL| > 5 dB) still exist in the Δ SEL plots, probably because of factors such as higher wind speeds, surrounding noise events, etc., that will require further investigation before the results can be finalized. The results shown here are intended to provide a sample of the statistical analysis capability currently under development at Georgia Tech and do not constitute final validation outcomes.

Preliminary Dashboard Development

A preliminary dashboard was developed as a tool to provide visual and meaningful representation of the data. To build the dashboard, the data are pre-processed, and a new Microsoft Excel spreadsheet serving as a template is constructed on the basis of four different files: monitors' location, the SFO FOQA dataframe of approach and departure, and the master results database. All these files are generated internally from AEDT. Specific tabs from the files above are pasted into a new Excel spreadsheet, and the parameters not used in building the dashboard are deleted. During pre-processing, only necessary parameters are extracted, to decrease the size of the file imported into the visualization tool and therefore shorten the processing time. The spreadsheet is imported into Tableau, each of the four tabs above is added, SFO arrivals and departure tabs are combined, and the microphone altitudes are matched with the noise and performance data by using the monitors' numbers. These noise events' data are in turn matched with the SFO dataframe data by using the unique flight ID.

To visualize the data, the generated Excel spreadsheet is imported into Tableau, and different plots are created (Figure 9). The first plot (middle top), the monitor location map, shows the exact positions of the monitors in SFO and their altitudes above sea level. Next (top right), the FOQA flight map shows the flight tracks for both departures (red) and arrivals (blue). Additionally, the performance plots (top, middle, bottom, and left) show the height above takeoff and touchdown, the ground speed, and the net average thrust for both departures (red) and arrivals (blue). These three plots do not require data manipulation, and the necessary parameters are dragged and dropped into the equivalent fields of Tableau's main window. Finally, the box plot (bottom right) shows the Δ SEL for all eight profiles. The results in Figure 9 are preliminary and are intended only to showcase the capability under development. The box plot requires pre-processing in Excel, because every row of data contains all profile types (FOQA_FPP, STD_APTW, AW_RT15, NADP1, NADP2, NADP1_AW_RT15, NADP2_AW_RT15, and STD_ASOS). The aim of the processing is to transpose profile types into multiple rows so that each data entry can be drawn as a separate curve. To ensure that the dashboard is interactive and user-friendly, all different plots are linked, and the data can be filtered out with the ground track ID, operation (departure or arrival), airframe, departure or arrival airport, noise class (overhead or sideline), whether the aircraft is flying over land or water, elevation angle, flap position, horizontal distance, and slant distance, The detailed process to create the dashboard by starting from the raw data files is explained in a separate set of internal documentation available from Georgia Tech.

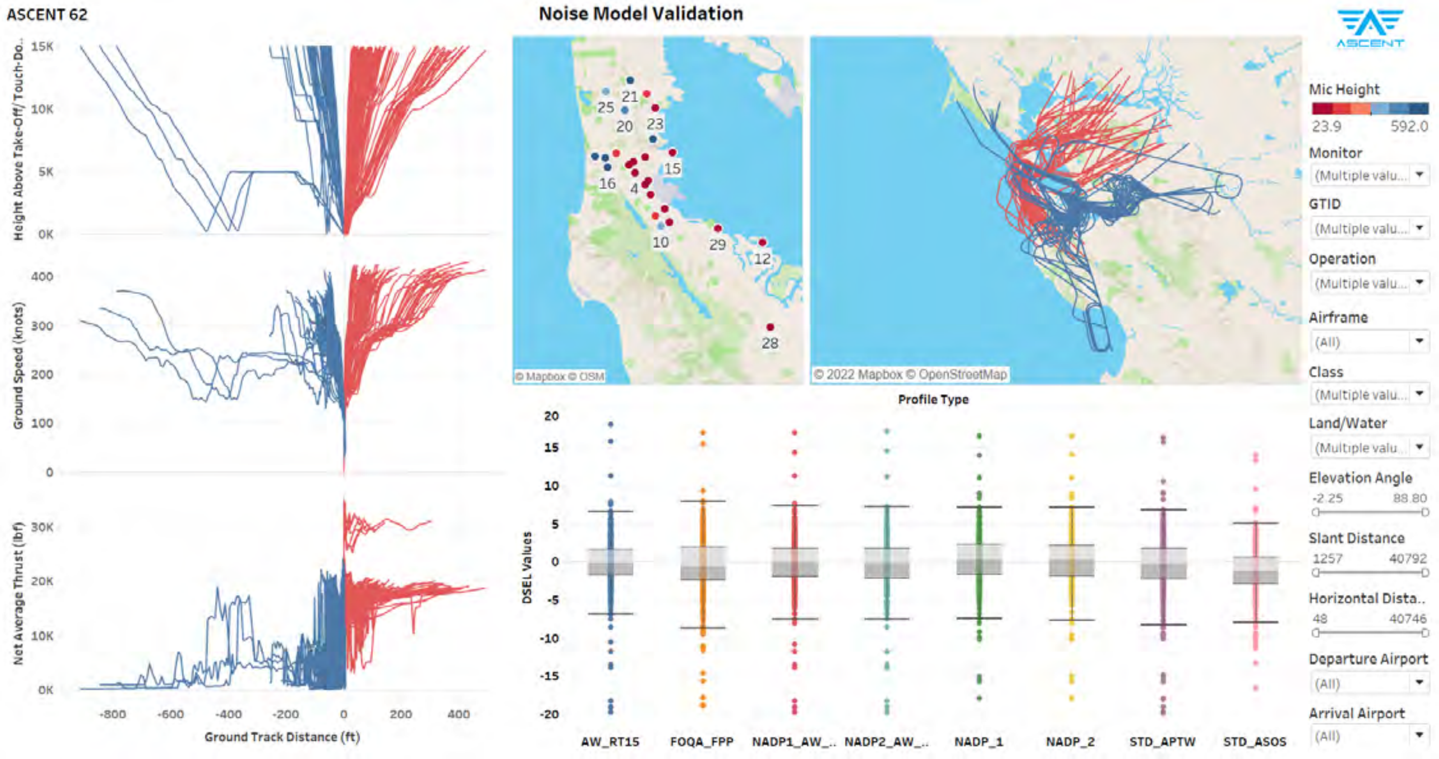


Figure 9. The final layout of the dashboard with the different visualization capabilities and filters.

Milestone(s)

None.

Major Accomplishments

Georgia Tech accomplishments

- Completed successful implementation of the AEDT automation pipeline for (a) modeling real-world flights in various settings, and (b) extracting and visualizing results from noise modeling efforts
- Successfully ran 269 flights at all identified settings from the test matrix, analyzed over 616 noise events (437 departures and 179 arrivals) to generate preliminary validation results.

Coordinated with the PSU team to provide flight data required for tasks relevant to PSU tasks

Publications

Bendarkar, M. V., Bhanpato, J., Puranik, T. G., Kirby, M., & Mavris, D. N. (2022, June 27). Comparative assessment of AEDT noise modeling assumptions using real-world data. AIAA AVIATION 2022 Forum. AIAA AVIATION 2022 Forum, Chicago, IL & Virtual. https://doi.org/10.2514/6.2022-3917

Outreach Efforts

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

Awards

None.

Student Involvement

Georgia Tech

Graduate research assistants: Sabastian Abelezele, Amber Willitt, and Wiame Benzerhouni

Plans for Next Period

In the next period, Georgia Tech plans to:

- Analyze the modeled noise events to evaluate the effects of different assumptions and aircraft or ambient conditions
- Provide insights into the statistical significance of results at various noise monitoring stations
- Develop the interactive dashboard containing the modeling results with all different settings combined for performing trade-off studies
- Work with PSU, the FAA, and various noise monitoring offices and airlines to expand the validation study to different airports

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Task 2 - Assessing the Use of High-Fidelity Meteorological Data in AEDT Noise Calculations

The Pennsylvania State University

Objective

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

AEDT noise model uses high-fidelity meteorological data only for performance calculations. For noise calculations, AEDT does not use high-fidelity meteorological data directly (for example, when calculating the Acoustic Impedance Adjustment or the Atmospheric Absorption Adjustment). As an exploratory step, PSU is investigating the possibility of incorporating high-fidelity meteorological data in AEDT noise calculations without modifying the noise model in AEDT.

Research Approach

AEDT's noise model currently assumes homogeneous weather conditions for noise calculations. The weather conditions used in noise calculations are typically ground-based measurements, such as the airport weather (typically an annual average). Although real-world weather is well known to rarely be homogeneous, the impact of meteorological inhomogeneity on AEDT's noise calculations must be investigated to determine whether it substantially improves AEDT's noise prediction capabilities. One possibility of incorporating high-fidelity weather data in AEDT's noise calculations is to explore the use of averages of meteorological variables (such as temperature and humidity) based on high-fidelity meteorological data. If this approach leads to a noticeable improvement in AEDT's noise calculations, it could enable AEDT's noise calculations to be improved without changing the existing integrated noise model in AEDT. To explore this possibility, the PSU team is working with real-world flight and noise measurement data provided by Georgia Tech for a flight departing from KSFO. The aircraft tracking data and performance results from AEDT (provided by Georgia Tech) are used by PSU in its in-house ray-tracing code to predict noise levels near the ground. A primary goal in this year's work has been to demonstrate confidence in the in-house ray-tracing code.

Aircraft trajectory and locations of noise monitors

The Georgia Tech team has provided the flight tracking data for a departing Boeing 737-800 from KSFO (anonymized flight ID: GT786D). Figure 10 shows the aircraft track associated with the flight and a color scale showing flight altitude above the mean sea level. The region marked by a dash-dotted blue line is shown in detail to draw attention to the nine noise monitoring stations around KSFO.

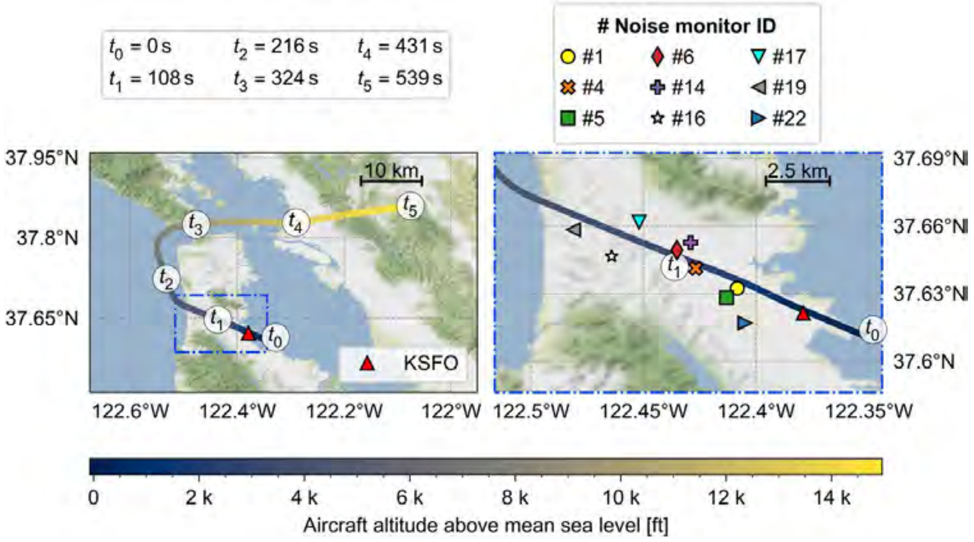

Figure 10. Aircraft trajectory and locations of the noise monitors around KSFO (anonymized flight ID: GT786D).

The noise monitor data available for this flight do not include the time history of the received noise but only the L_{Amax} (*A*-weighted maximum sound level) and the SEL (*A*-weighted sound exposure level). The data for this flight are used for conducting numerical experiments using an acoustic ray-tracing code developed in-house to predict noise levels at the noise monitor locations.

Comparison of meteorological conditions

Meteorological conditions play an important role in correctly modeling noise propagation. Specifically, the temperature and humidity conditions play a critical role, because they affect the propagation path as well as the atmospheric absorption. For the event under investigation, Figure 11 shows the relevant temperature and specific humidity profiles. In Figure 11, the inhomogeneous meteorological profiles obtained near KSFO from the Spire Global data are shown with a black line. As indicated in Figure 10, the portion of the flight relevant for the noise measurements involves aircraft altitudes less than 2 km. Hence, an average of the Spire Global data over all heights from 0 to 2 km is an important abstraction of interest (shown with a dash-dotted blue line in Figure 11). Finally, the airport weather data for KSFO, as given in AEDT, are shown with a dashed red line in Figure 2. Clearly, the annual average airport weather (as given in AEDT) will not always accurately represent the meteorological conditions for a specific event; therefore, ideally, the inhomogeneous data shown by the black line (Spire Global data) in Figure 11 would be used. Modifying the existing integrated noise model in AEDT to include inhomogeneous meteorological data for noise calculations will be challenging. Instead, if using average weather conditions based on the inhomogeneous data (dash-dotted blue line Figure 11) satisfactorily improves the noise predictions (in comparison to annual average weather), this change in AEDT would be easier to implement. To investigate this possibility, the PSU team has set out to first try to mimic AEDT's noise model by modifying a general-purpose acoustic ray-tracing code developed in-house. If successful, the PSU team can then modify the in-house code to calculate the noise by using both the inhomogeneous meteorological data and the average weather based on the inhomogeneous data.

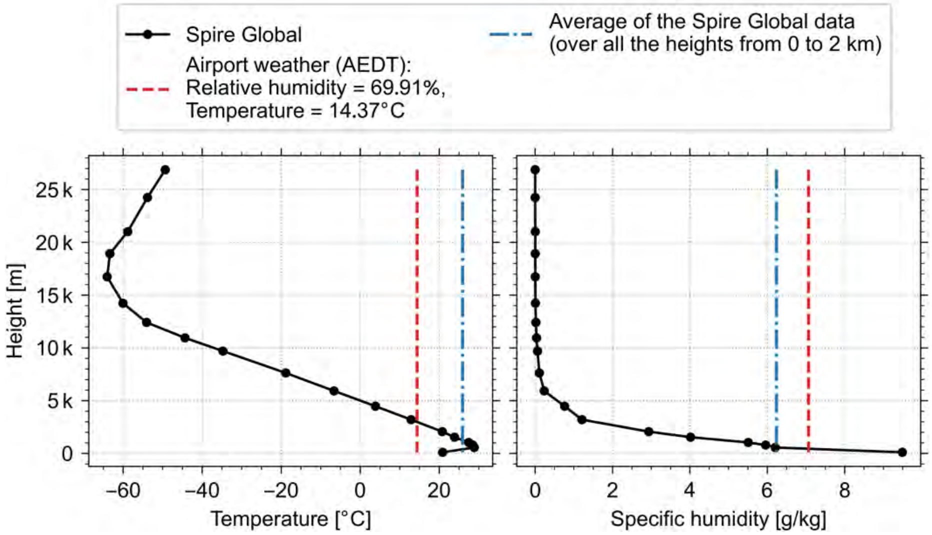

Figure 11. Comparison of the temperature and specific humidity profiles from AEDT and Spire Global data for flight GT786-D.

Attempting to reproduce AEDT's noise calculations by using PSU's in-house code

Before attempting to use meteorological data other than the airport weather in noise calculations, demonstrating confidence in the in-house code developed at PSU is crucial. This area has been a primary focus of the work performed over the past year at PSU. Apart from specifying meteorological profiles, PSU's in-house ray-tracing code requires the source levels at 1 m from the aircraft. The thrust-dependent source levels are obtained by using the time history of thrust values obtained from AEDT's performance report (provided by the Georgia Tech team). The thrust levels are used with the spectral class data and the NPD tables from AEDT to obtain the correct source levels. As noted in the AEDT 3d technical manual (Lee, 2021), the NPD data implicitly contain absorption for the reference day conditions, as specified in SAE-AIR-1845 (SAE International, 1995). The source levels used in the in-house code have been extracted by carefully removing the built-in atmospheric absorption as well as the spherical spreading assumed in the NPD data. The in-house ray-tracing code is then used to propagate the noise to the noise monitors, accounting for the aircraft trajectory and the locations of the noise monitors. Atmospheric absorption is then applied according to SAE-ARP-5534 (SAE International, 2013). The in-house code has a provision to include the effect of ground impedance as well as user-specified aircraft directivity information. Because the goal is to match AEDT's predictions, the PSU team used the Lateral Attenuation Adjustment, as defined in the AEDT 3d technical manual (Lee, 2021), to account for ground reflection, refraction, airplane shielding, and engine installation effects. During this investigation, we noted that the correct use of lateral attenuation adjustment brought the in-house predictions significantly closer to AEDT's predictions.

Preliminary results comparing AEDT and in-house code

The Georgia Tech team ran an AEDT study with the FOQA data by using the fixed-point procedural profile and the airport weather to provide noise predictions at the noise monitor locations shown in Figure 10. These results were compared with the noise predictions obtained with PSU's in-house code assuming homogeneous weather as in AEDT (dashed red line in Figure 11). Table 4 shows the difference between the in-house noise predictions and the AEDT noise predictions for the maximum A-weighted sound pressure level (LA_{max}) and the A-weighted SEL. Reassuringly, the noise prediction using PSU's in-house code, as modified to match AEDT, closely matches AEDT's prediction, with only two calculations exceeding a 1-dB difference.

Table 4. Difference between the in-house noise predictions and AEDT's noise predictions across multiple monitors.

Monitor ID	**1**	**4**	**5**	**6**	**14**	**16**	**17**	**19**
Δ LA_{max} (dBA)	−0.35	−0.32	−0.7	−0.38	−0.74	−1.24	−0.86	−0.38
Δ SEL (dBA)	0.21	1.02	−0.22	0.86	0.24	−0.35	0.07	0.57

Importantly, the in-house code performs point-to-point (propagation from a point source to a point receiver) calculations, whereas AEDT uses an integrated noise model that calculates noise metrics as an aggregate over multiple segments in flight. This distinction might explain the differences in noise predictions in Table 4. This exercise has improved the PSU team's understanding of AEDT's noise model and has supported confidence in the in-house code. In the next project period, PSU's validated in-house code will help in assessing the inclusion of high-fidelity meteorological data for noise calculations in AEDT.

Understanding AEDT's acoustic impedance and atmospheric absorption adjustments

In parallel with the above comparison between PSU's in-house code and AEDT's noise calculations, PSU is continuing efforts to gain a deeper understanding of the AEDT noise calculation. By having a clear understanding of the contributions to the AEDT noise calculation, and how each contribution is affected by high-fidelity meteorology, the project can assess the potential benefits or drawbacks of including high-fidelity data in a future release of AEDT.

When calculating noise level adjustments due to weather, AEDT defaults to single yearly averages for each airport, thus effectively treating the propagation path (atmosphere) as homogeneous, which is not necessarily a realistic assumption. PSU has been examining the use of high-fidelity weather data from Spire Global in calculating the acoustic impedance adjustment (AI_{adj}), an important contributor to the AEDT noise calculation. AI_{adj} depends on air density and the speed of sound, which can be found through the air temperature and barometric pressure given in the Spire Global data by using thermodynamics. Through processing the Spire Global data and calculating the density and sound speed, AI_{adj} is visualized in a 2D map over KSFO (assuming dry air and no wind) in Figure 12.

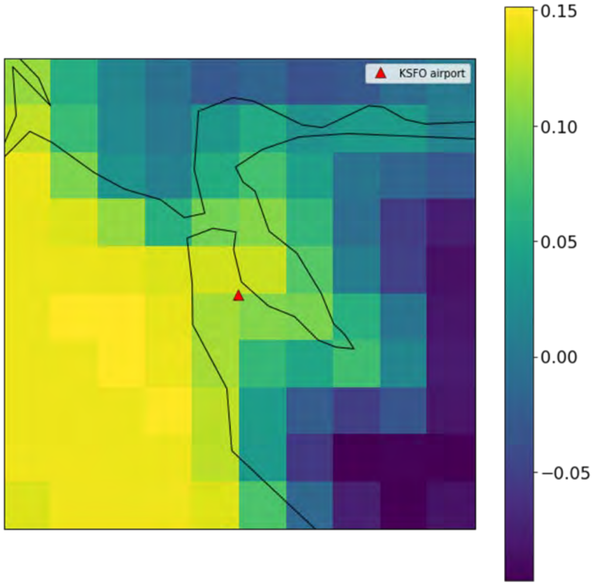

Figure 12. Top-down view of AI_{adj} in a 139 × 139 km grid around KSFO, assuming a constant height.

This visualization shows an AI_{adj} value range from approximately −0.2 dB to 0.15 dB. The variation occurs over regions that differ geographically (e.g., over the land north and south of the airport as well as the ocean to the west). The value relies on the variation in air temperature. This model accounts for only a single isobaric level at one time, but 3D models of the environment were also created, with AI_{adj} calculated by using the full set of high-fidelity weather data (Figure 13).

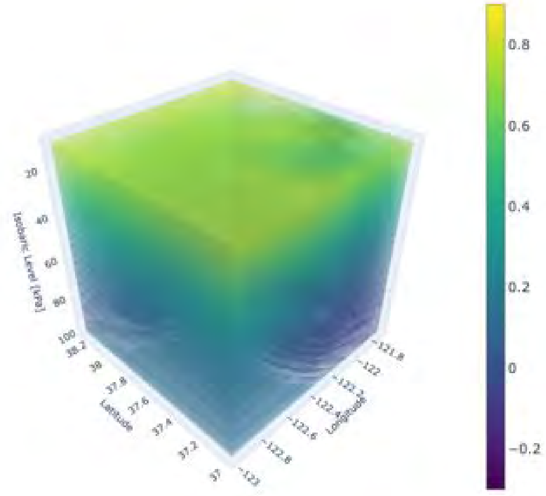

Figure 13. 3D view of AI_{adj} in the space around KSFO with the same geographic extent as in Figure 12. The elevation shown here ranges from 90 to 16,680 m (295 to 54,725 feet).

For this set, AI_{adj} ranges from approximately −0.2 dB to 0.8 dB, which is notably larger than the range in the 2D model. Because the full set of data covers a very large range of altitudes, and flight operations typically occur in only the lowest 2 km of the atmosphere, a separate model was created in which only the first 2 km of atmosphere is considered (Figure 14).

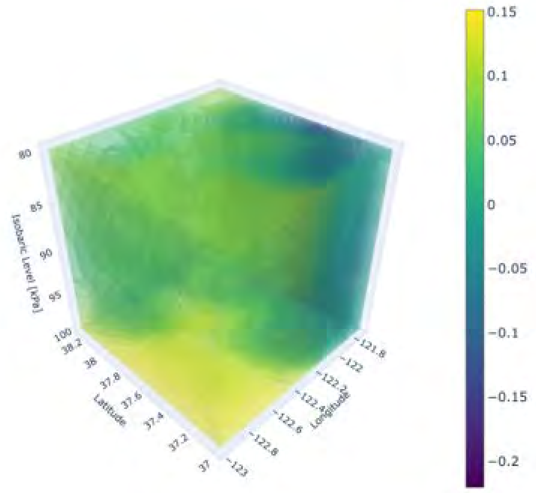

Figure 14. Three-dimensional view of AI_{adj} in the space around KSFO with the same geographic extent as in Figure 12. Of note the elevation shown here ranges from only 90 m to 2 km. The colors shown closest to the ground are identical to those in Figure 12.

The AI_{adj} value range in Figure 14 is lower than that in Figure 13, and shows the variation over space more clearly. These visualizations indicate that AI_{adj} varies considerably around KSFO . Currently, AEDT uses the value of AI_{adj} at the airport for the noise calculation. However, a flying aircraft is not always at the airport location. Hence, future work will investigate whether using a value of AI_{adj} based partially or entirely on the 3D aircraft location improves AEDT noise predictions.

Ongoing work in a preliminary stage of development is also assessing the atmospheric absorption adjustment (AA_{adj}), another contributor to AEDT's noise prediction. On the basis of previous ASCENT projects, 3D meteorology is expected to profoundly influence the calculation of atmospheric absorption, and AA_{adj} will have a larger impact on noise calculations than that seen for AI_{adj}.

PSU has also been in contact with Washington Metropolitan Airports Authority regarding the use of their noise monitor data for upcoming validation efforts in the next phase of the work.

Milestones

None.

Major Accomplishments

(The project started in July 2020)

PSU accomplishments

- PSU's in-house ray-tracing code is predicting noise near the ground within 1 dB of the predictions by AEDT, thereby suggesting the legitimacy of the in-house code. This step is important in investigating the potential use of high-fidelity weather in AEDT.

Publications

Shaw, E., & Sparrow, V. (2022). Modeling acoustic impedance and atmospheric absorption around airports using high-fidelity weather data. *NOISE-CON Congress and Conference Proceedings*, *264*(1), 104–110. https://doi.org/10.3397/NC-2022-698

Outreach Efforts

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

Awards

None.

Student Involvement

PSU
Graduate research assistants: Harshal Patankar and Emma Shaw.

Plans for Next Period

In the next period, PSU plans to:

- Continue to support the Georgia Tech team, consider the differences in AEDT noise predictions with and without high-fidelity weather, and assess whether updating the atmospheric absorption and acoustic impedance adjustments with high-fidelity weather will have a noticeable effect on AEDT noise predictions
- Assess the use of averages based on the high-fidelity weather data as an input to the AEDT noise model instead of using ground-based weather measurements
- Advance understanding of the acoustic impedance and atmospheric adjustments used in AEDT noise predictions
- Continue working with the Washington Metropolitan Airports Authority and other airports, as needed, to support ongoing and future AEDT noise validation efforts in conjunction with Georgia Tech, as advised by the FAA
- Provide the relevant high-fidelity meteorological data to support the AEDT noise model validation work being conducted by Georgia Tech (using high-fidelity meteorological data obtained by PSU either through collaboration with Spire Global [www.spire.com] or from alternative sources if needed, as demonstrated in the ASCENT Project 062 annual report in 2021 (Shaw & Sparrow, 2022).

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