Project 062 Noise Model Validation for AEDT

Georgia Institute of Technology
The Pennsylvania State University

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- FAA Award Number: 13-C-AJFE-GIT Amendments 106, 125, and 144
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- FAA Award Number: 13-C-AJFE-PSU, Amendments 59, 83, 89, and 106
- Period of Performance: October 1, 2021 to September 30, 2024
- Tasks:
    1. Noise modeling in the Aviation Environmental Design Tool (AEDT) with automation (Georgia Tech) 2. Assessing the use of high-fidelity meteorological data in AEDT noise calculations (PSU)

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 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 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, close 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, et al. (2020)

and Behere, Isakson, et al. (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 et al., 2019; Monteiro et al., 2018), in comparing aviation environmental impact mitigation strategies (Yu & Hansman, 2019), and in various other community noise quantification studies (Yu & Hansman, 2019; Salgueiro et al., 2021; Thomas & Hansman, 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, et al., 2021) or for estimating the impacts of average types of operations at different airports (Behere, Bhanpato et al., 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) investigated a 1997 data set from Denver International Airport (DEN) to determine how INM's prediction accuracy changed with different thrust prediction methods. They 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 & 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 the introduction of AEDT by the FAA in 2015, numerous studies have been performed on it. Hobbs et al. (2017) 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 et al., 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.

Giladi & Menachi (2020) developed a methodology to validate the AEDT noise model using published flight paths and Automatic Dependent Surveillance-Broadcast (ADS-B) data at three different locations. They found AEDT to underestimate actual noise levels based on a handful of operations. Following a similar methodology, Jackson et al. (2021) developed an automated framework for modeling large datasets of real-world flight trajectories in AEDT using ADS-B data. Alonso (2023) reports preliminary findings of that framework applied to over 86,000 arrival operations at SFO for a couple of noise monitor locations. In a study using flight operations quality assurance (FOQA) data for AEDT noise model validation, Gabrielian, Puranik, Bendarkar, Kirby, Mavris, & Monteiro (2021) presented an automated framework to model FOQA data as fixed-point profiles (FPPs) within AEDT. This was followed by an evaluation of AEDT's noise prediction capability while using high-fidelity weather data (Gabrielian, Puranik, Bendarkar, Kirby, & Marvis, 2021). Shaw & Sparrow (2022) investigated acoustic impedance and atmospheric absorption using high-fidelity meteorological data to improve the AEDT noise model. Further work on using appropriate averages based on inhomogeneous meteorological profiles, instead of relying on homogeneous annual average weather, to improve noise predictions is presently underway (Mavris & Sparrow, 2022). Preliminary results of a comparative assessment of AEDT noise modeling assumptions at SFO were presented last year (Bendarkar et al., 2022).

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, Bendarkar, Kirby, Mavris, & Monteiro, 2021; Bendarkar et al., 2022). Two important elements in this modeling are summarized herein for completeness: (1) the data sources used during modeling, and (2) 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. ***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" (Federal Aviation Administration, 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 & Mavris, 2018; Lee et al., 2020). The important elements of the FOQA data in this report 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 the maximum, A-weighted sound level (L_{max}) metrics of associated noise events. The flight ID and the time of closest approach in the noise monitor data allow 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 report 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 two airports, SFO and Seattle-Tacoma International Airport (SEA). Noise monitoring readings obtained from the SFO airport noise program (SFO, n.d.) include SEL and L_{max} noise event details. Noise data from SEA noise office included SEL and L_{max} readings for the entire year in addition to 1-second equivalent sound level (L_{eq}) time history data from July through December 2019.

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			

** Based on stage length.
RT – Reduced Thrust (5 or 10 or 15 percent).
NADP – Noise Abatement Departure Profile (1 or 2)
NPD+C – Noise Power Distance + Correction

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			

** Arrival thrust is calculated using force-balance.
ASOS – Automated Surface Observing System
NPD+C – Noise Power Distance + Correction

SFO was 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. For the SEA airport, a total of 71 and 80 departure and arrival flights with 179 and 105 noise events, respectively, have been identified using the time-series noise data matched to FOQA data. These flights consist of Boeing 717-200, 737-800, 737-900, 757-200, 757-300, 777-200ER/LR, 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 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 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:*** Standard departure weight is defined by trip distance (stage length) within AEDT. Modified alternative weight procedures are available within AEDT that can be combined with the standard or reduced thrust procedures. Alternatively, FOQA weight can be used for AEDT procedures. FOQA weight can also be used within AEDT while employing FPPs. However, weight does not affect noise computation for FPPs because all performance parameters, such as thrust, are already prescribed. 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 along with the extended runway centerline 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 compared 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 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, 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, AEDT default values of soft ground surface and flat terrain are used.

7. ***Flaps and landing gear:*** The flap and gear schedule for modeling in AEDT are provided with each of the procedures. For FOQA FPPs, AEDT infers a flap and gear schedule from the corresponding standard profile. However, unless the analysis is using NPD data with correction for configurations, the flap and gear configuration does not affect the calculated noise when using an FPP. The present work visualizes the errors in AEDT SEL predictions against FOQA flap and gear settings because these affect the real-world noise measured at monitoring stations.

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. Arrival profiles 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 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).

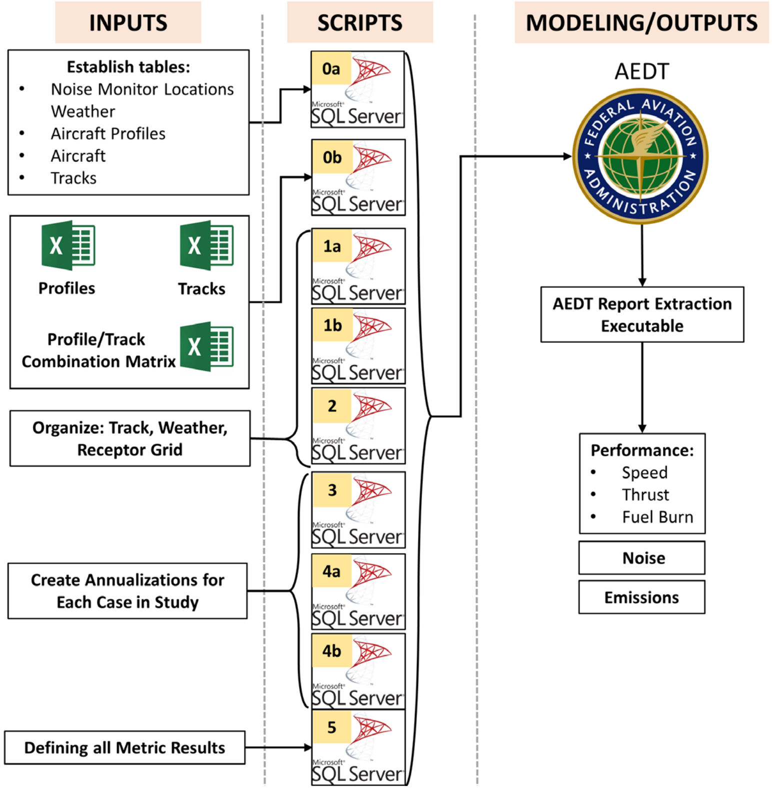

Figure 1. Noise modeling process automation steps. AEDT, Aviation Environmental Design Tool.

Preliminary Results

The results for SEA are presently under analysis and will be reported in subsequent reports. The present work focuses on results from SFO. 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 an aggregate basis.

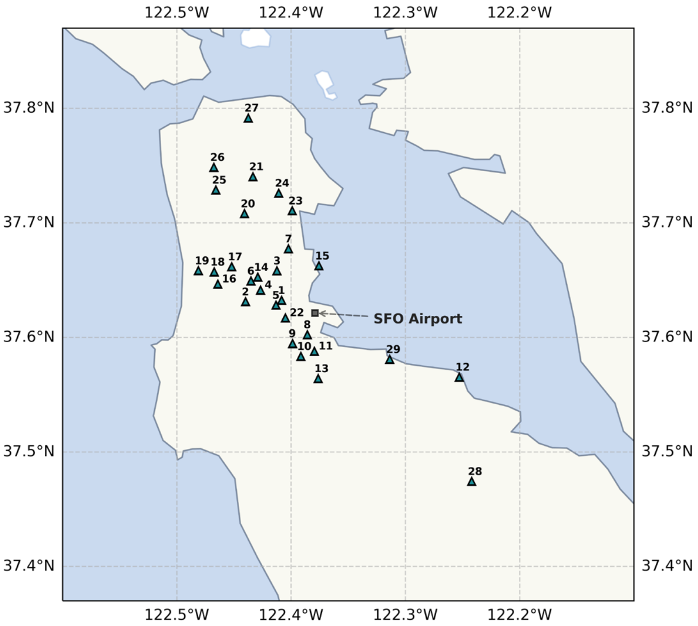

Figure 2. Locations of noise monitors around San Francisco International Airport (SFO).

Figure 2 shows the locations of noise monitors around SFO, and Figure 3 shows the modeled FOQA arrival and departures tracks at 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.

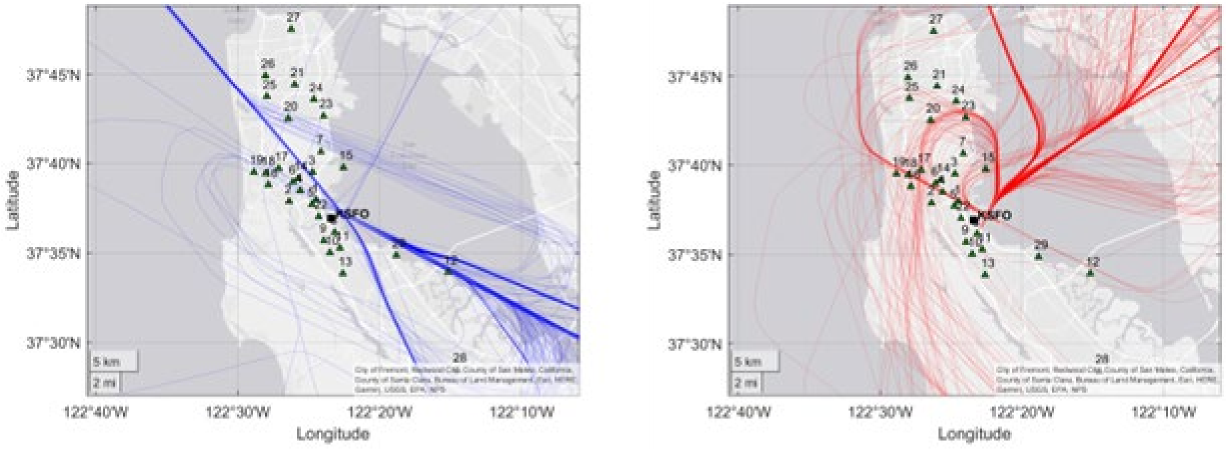

Figure 3. Arrival (left) and departure (right) flight operational quality assurance (FOQA) tracks at San Francisco International Airport (SFO).

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	61	1,018.3	53.1	75.2	9	N/A

Flight number GT1015
Flight GT1015 was a Boeing 737-800 with an origin–destination 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 4 shows the performance plots for flight GT1015, as part of the data extracted from AEDT with the AEDT report extraction executable. The aircraft performance, based on procedural profiles, shows that the alternative weight reduced thrust 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 5. The noise comparison for flight GT1015 in Figure 6 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 5. 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.

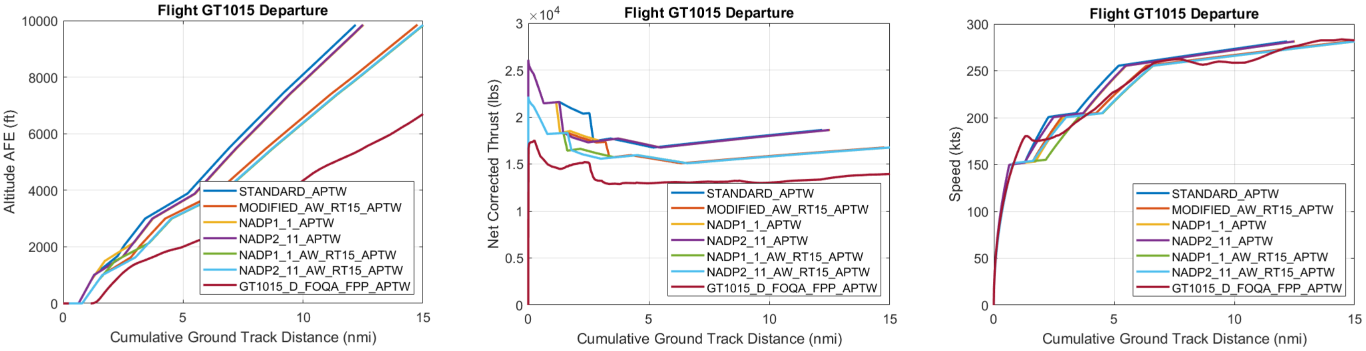

Figure 4. Altitude, thrust, and ground speed performance for flight GT1015. _APTW – profile with airport weather. _AW_RT15 – Alternate Weight Reduced Thrust 15% . NADP – Noise Abatement Departure Procedure (1 or 2). FOQA_FPP – Flight Operations Quality Assurance Fixed Point Profile.

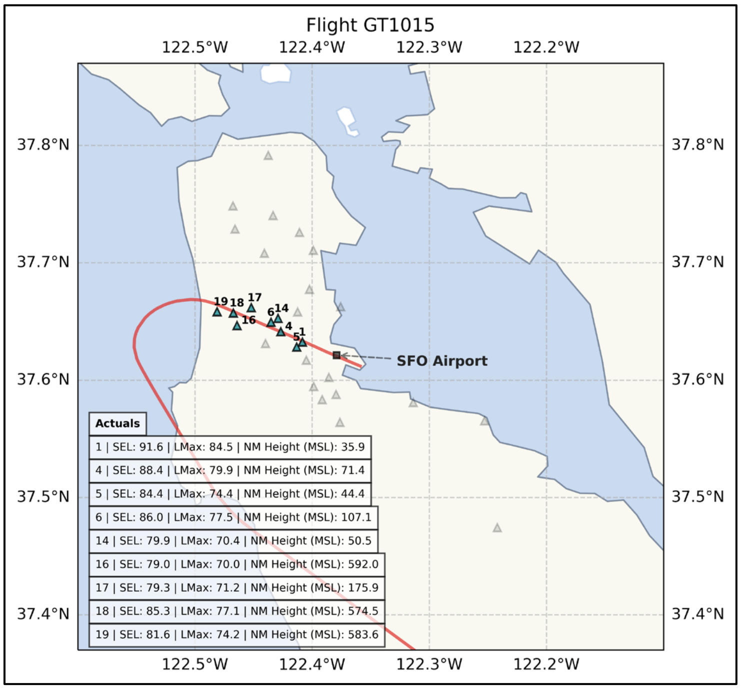

Figure 5. Trajectory and monitors triggered for flight GT1015. SFO, San Francisco International Airport; SEL, sound exposure level.

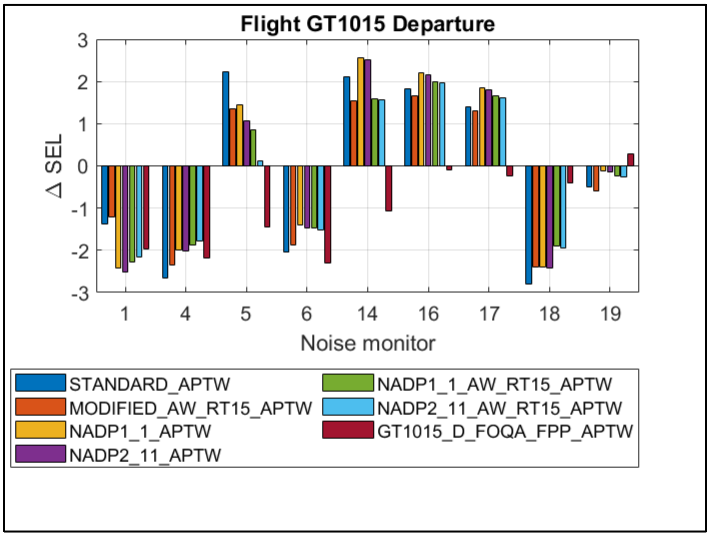

Figure 6. AEDT predicted – measured noise (dB) results for flight GT1015. SEL, sound exposure level.

Identifying outliers

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

Based on preliminary observation of the data, several anomalous factors were identified. Results from flights that triggered monitor 8 consistently had high ΔSEL. 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 ΔSEL 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 anomalous factors, some flights with high ΔSEL remained. Noise events with wind speeds >10 knots or nonzero precipitation, as observed by hourly Automated Surface Observing System (ASOS) weather data, were excluded from further analysis since AEDT is not designed to predict noise in these circumstances. Slant distances over 10,000 ft were investigated to determine what threshold produced high SEL prediction errors. Noise events with higher slant distances have an increased possibility of inaccurate noise measurements or event correlation to flight due to uncontrollable factors like background noise levels. Additionally, 29 noise events with slant distances between 7,000 and 10,000 ft were found to have elevation angles less than 1°. Since these are likely incorrect correlations between noise monitoring data and flight operations, they were dropped.

Due to such exclusions, the total useful noise events reduced to 142 and 51 for 63 departure flights and 51 arrival flights, respectively, from a total of 616 noise events (437 departures and 179 arrivals) initially. Table 4 shows a summary of the outlier analysis and the total data points that will be presented in the aggregate results. It is important to note here that all arrival noise events in the useful total were captured by just one monitor at SFO: Monitor 12, as shown in Figure 2. Therefore, prediction errors in arrival noise events would be influenced by unknown extraneous factors such as monitor location and background/other noise sources to a greater extent than departure events.

Table 4. San Francisco International airport (SFO) outlier analysis

Operation	Flights	Noise Events	Comments
Arrivals	140	179	Modeled
		-44	Wind >10 knots or nonzero precipitation
		-36	Abnormal track
		-15	Monitor 8
		-33	Slant distance >7,000 ft or Misc.
	51	**51**	**Useful total**
Departures	129	437	Modeled
		-213	Wind >10 knots or nonzero precipitation
		-37	Monitor 8
		-45	Slant distance >7,000 ft or Misc.
	63	**142**	**Useful total**

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 193 noise events in this section. To this end, prior work provided preliminary results for per-noise-monitor prediction capability for departure flights (Mavris & Sparrow, 2022). Instead of viewing one flight at a time, all flights that triggered a particular noise monitor were considered at each profile. This report presents results for SEL prediction errors for all aggregated noise event across all monitors by departure and arrival operations. These results are further sliced by different data parameters that are only available via the FOQA data, like landing gear and flap settings, takeoff and landing weights, elevation angles and slant distances, etc. The eight profiles for the departure operations modeled in AEDT 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 arrival operations have been modeled using the Standard profile with average airport weather (STD_APTW) and FOQA FPPs (FOQA_FPP). The difference between the AEDT predictions and measured noise observations for all monitors is computed and analyzed with box plots. This metric is referred to as the ΔSEL metric and is defined in Eq. (1). 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.

$$\Delta SEL = SEL_{AEDT} - SEL_{Measured} \tag{1}$$

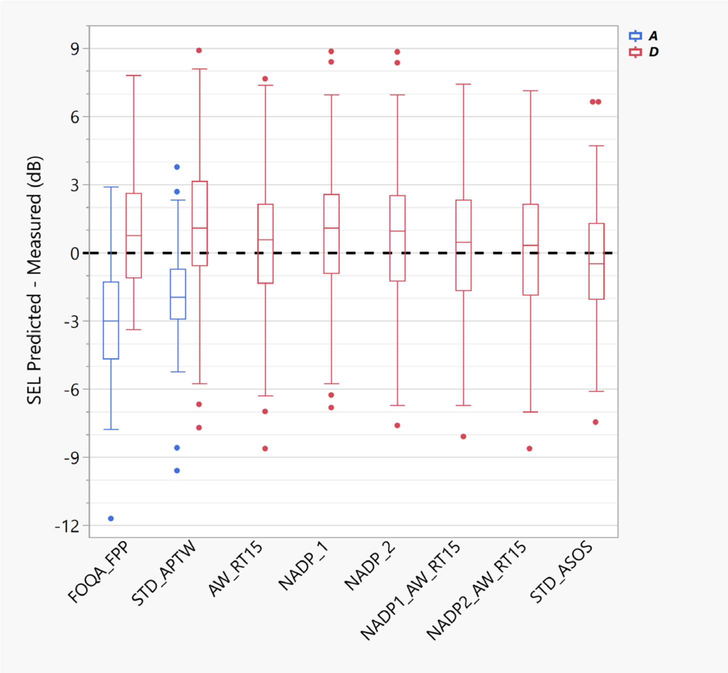

Figure 7. Predicted − measured sound exposure level (SEL) (dB) noise box plot for all noise events at all monitors split by arrivals (A) and departures (D). _APTW – profile with airport weather. _ASOS – Profile with automated surface observing system weather. _AW_RT15 – Alternate Weight Reduced Thrust 15% . NADP – Noise Abatement Departure Procedure (1 or 2). FOQA_FPP – Flight Operations Quality Assurance Fixed Point Profile.

Figure 7 shows the error in SEL prediction minus SEL measurement (ΔSEL metric) for all noise events aggregated by departures and arrivals. All modeled departure profiles (D) show a median overprediction error of less than 1 dB, with the FOQA profile having the lowest variability. The arrival profiles (A) show a median underprediction error of around 2 to 3 dB. As stated earlier, all of the analyzed arrival events were captured by just one noise monitor (Monitor 12). The median error could therefore be influenced by other factors beyond our control.

Since the FOQA ground tracks are used with all modeled profiles, every noise event can be categorized based on the slant distance and elevation angle of the aircraft with respect to the noise monitor, as shown in Figure 8. For the analysis that follows, a noise event is considered overhead if the elevation angle is ≥50˚, and is sideline otherwise. Slant distances over 7,000 ft were found to cause disproportionately higher prediction errors. Due to absence of time-history noise data, it was difficult to associate these noise events with aircraft operations with high precision. As a result, all noise events above 7,000 ft slant distances have been removed from the results discussed below.

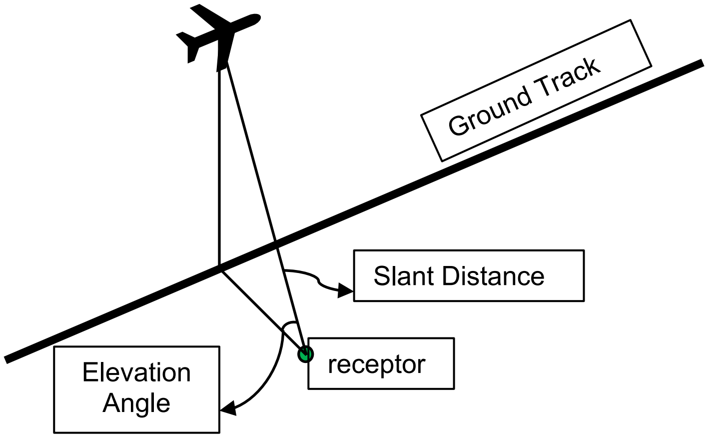

Figure 8. Notional representation of elevation angle and slant distance.

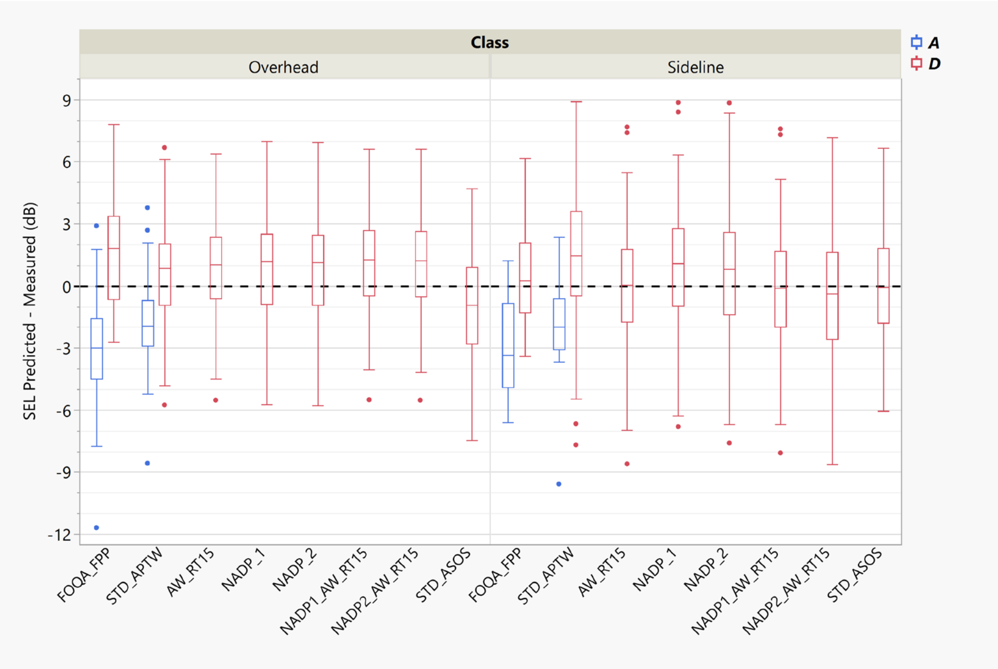

Figure 9. Predicted − measured sound exposure level (SEL) (dB) for overhead versus sideline noise events across all monitors. A, arrival; D, departure. _APTW – profile with airport weather. _ASOS – Profile with automated surface observing system weather. _AW_RT15 – Alternate Weight Reduced Thrust 15% . NADP – Noise Abatement Departure Procedure (1 or 2). FOQA_FPP – Flight Operations Quality Assurance Fixed Point Profile.

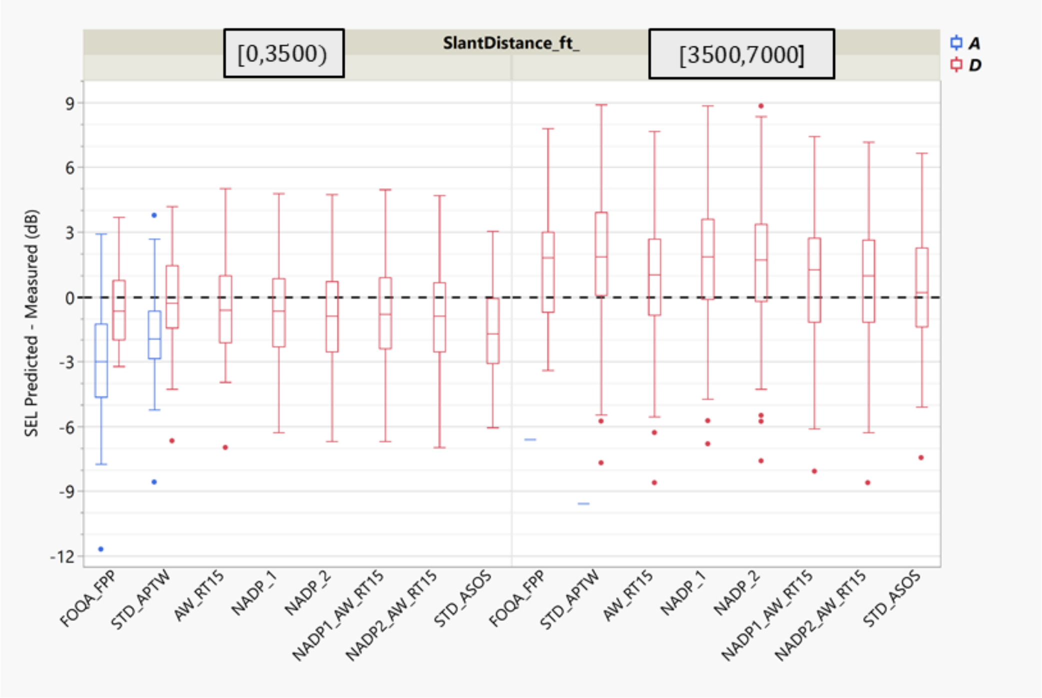

Figure 10. Predicted − measured sound exposure level (SEL) (dB) by slant distance across all monitors. A, arrival; D, departure. _APTW – profile with airport weather. _ASOS – Profile with automated surface observing system weather. _AW_RT15 – Alternate Weight Reduced Thrust 15% . NADP – Noise Abatement Departure Procedure (1 or 2). FOQA_FPP – Flight Operations Quality Assurance Fixed Point Profile.

Figure 9 shows the ΔSEL metric for 93 overhead and 100 sideline noise events. Median of arrival noise events suggests an underprediction for both classes, whereas departure event medians are overpredicted, with the FOQA profile showing a median closer to zero for sideline noise events with the smallest variation. For variation with slant distances, Figure 10 shows that the 45 departure noise events where the aircraft is closer than 3,500 ft to the noise monitors are predicted well, with a median ΔSEL of close to zero or −1, whereas the 97 departure noise events with slant distances greater than 3,500 ft tend to be overpredicted. The 51 arrival noise events all lie within 3,500 ft of Monitor 12 during approach.

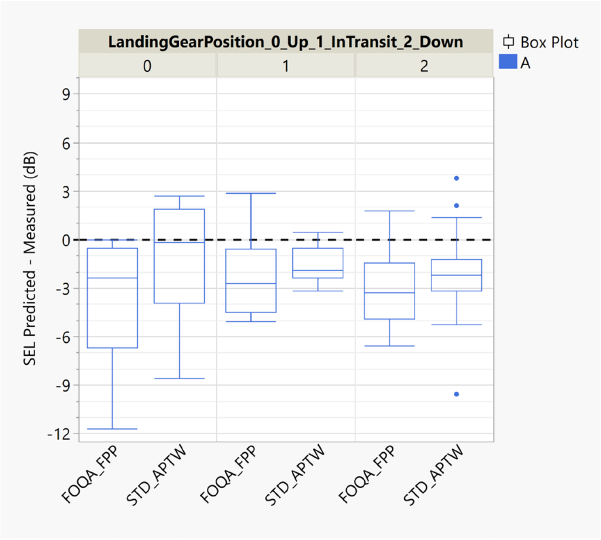

Figure 11. Predicted − measured sound exposure level (SEL) (dB) by landing gear position for all arrivals (A). _APTW – profile with airport weather. STD – Standard profile. FOQA_FPP – Flight Operations Quality Assurance Fixed Point Profile.

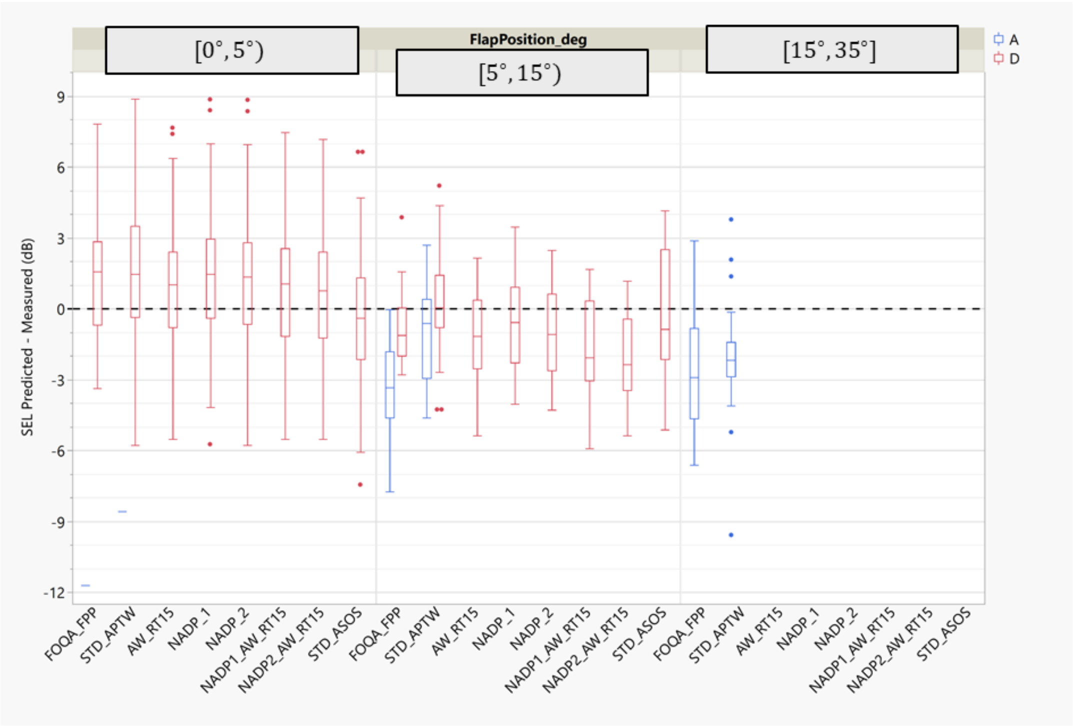

Figure 12. Predicted − measured sound exposure level (SEL) (dB) by flap positions for all noise events. A. arrival; D, departure. _APTW – profile with airport weather. _ASOS – Profile with automated surface observing system weather. _AW_RT15 – Alternate Weight Reduced Thrust 15% . NADP – Noise Abatement Departure Procedure (1 or 2). FOQA_FPP – Flight Operations Quality Assurance Fixed Point Profile.

Figure 11 shows ΔSEL for arrival operations by landing gear position when the aircraft are closest to the noise monitors in their trajectories. A value of 0 indicates the landing gear is up, 1 indicates it is in transit, and 2 indicates that the landing gear is down. In all three cases, the FOQA FPPs show a median underprediction of about 2 to 3 dB. When the landing gear is up, the standard profile has a median ΔSEL of zero but underpredicts by about 3 dB when the gear is in transit or down. Similarly, Figure 12 shows ΔSEL values for all operations by the flap position when the aircraft are closest to the noise monitors in their trajectories. Because the FOQA data often provides approximate decimal values instead of exact flap settings (e.g., 4.65˚ instead of 5˚, or 28.23˚ instead of 30˚), the results are divided into the three bins shown. The 115 departure noise events were found with flap angles of between [0˚, 5˚) at the time of triggering noise monitors. All profiles except the standard profile with ASOS weather are found to overpredict SEL values in that group. Between [5˚, 15˚), the 22 departure noise events are generally underpredicted by 1 dB, with the FOQA profile having the least variability. The 14 arrival events in this group and another 36 arrival events are generally underpredicted by 2 to 3 dB.

Figure 13 shows a histogram of the various airframes within the flights that are being analyzed in Table 4. The 737-900 and 737-800 are well represented, with scant representation of other airframes in the present analysis. Balancing the data for other airframes will be explored in future work for other airports and years of noise data. Figure 14 shows the weight error between AEDT assumptions and real-world FOQA operations by the stage length and airframe of interest. That AEDT underpredicts weights due to lower assumed load factors is well studied and has resulted in alternative weight profiles to account for these differences (Mavris et al., 2018). This is confirmed in the present work across the different airframe types.

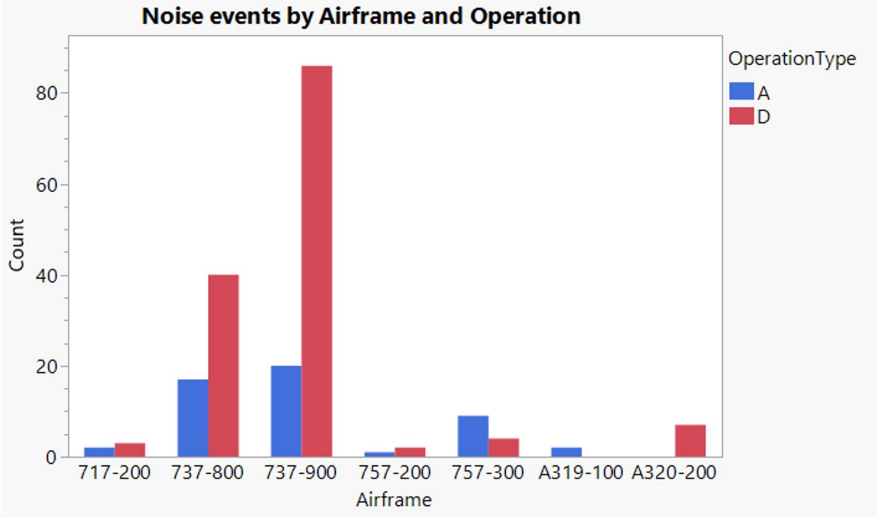

Figure 13. Noise events by airframe type and operation. A, arrival; D, departure.

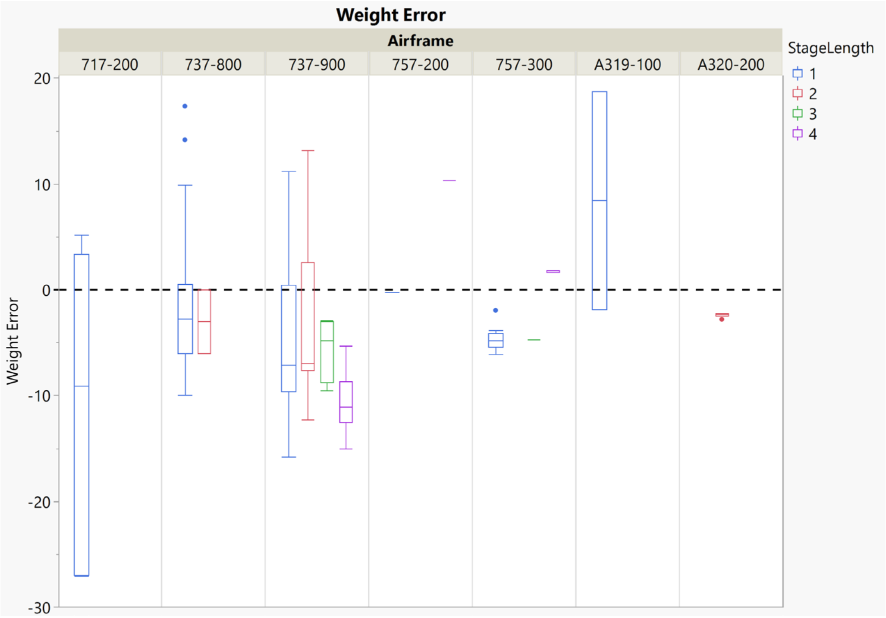

Figure 14. Aviation Environmental Design Tool (AEDT) weight assumption error $\left(\frac{\mathbf{Weight_{AEDT}} - \mathbf{Weight_{FOQA}}}{\mathbf{Weight_{AEDT}}} * \mathbf{100}\right)$.

The effect of these weights shows up during modeling through the stage length, which are decided based on the distance between origin-destination pairs of the flights, typically in 500-nmi increments. Figure 15 shows the effect of stage length on noise predictions through the ΔSEL metric given in Eq. (1). The total number of departure noise events in stage lengths 1, 2, 3, and 4 were 72, 19, 5, and 43, respectively. All arrivals are modeled as stage length 1 and are therefore not of consequence in this case. For departures, median ΔSEL values for stage length 4 flights are close to zero, with a majority of the overprediction happening in stage length 1 (0 to 500 nmi range) flights. It is difficult to draw conclusions for stage lengths 2 and 3 due to limited sample sizes.

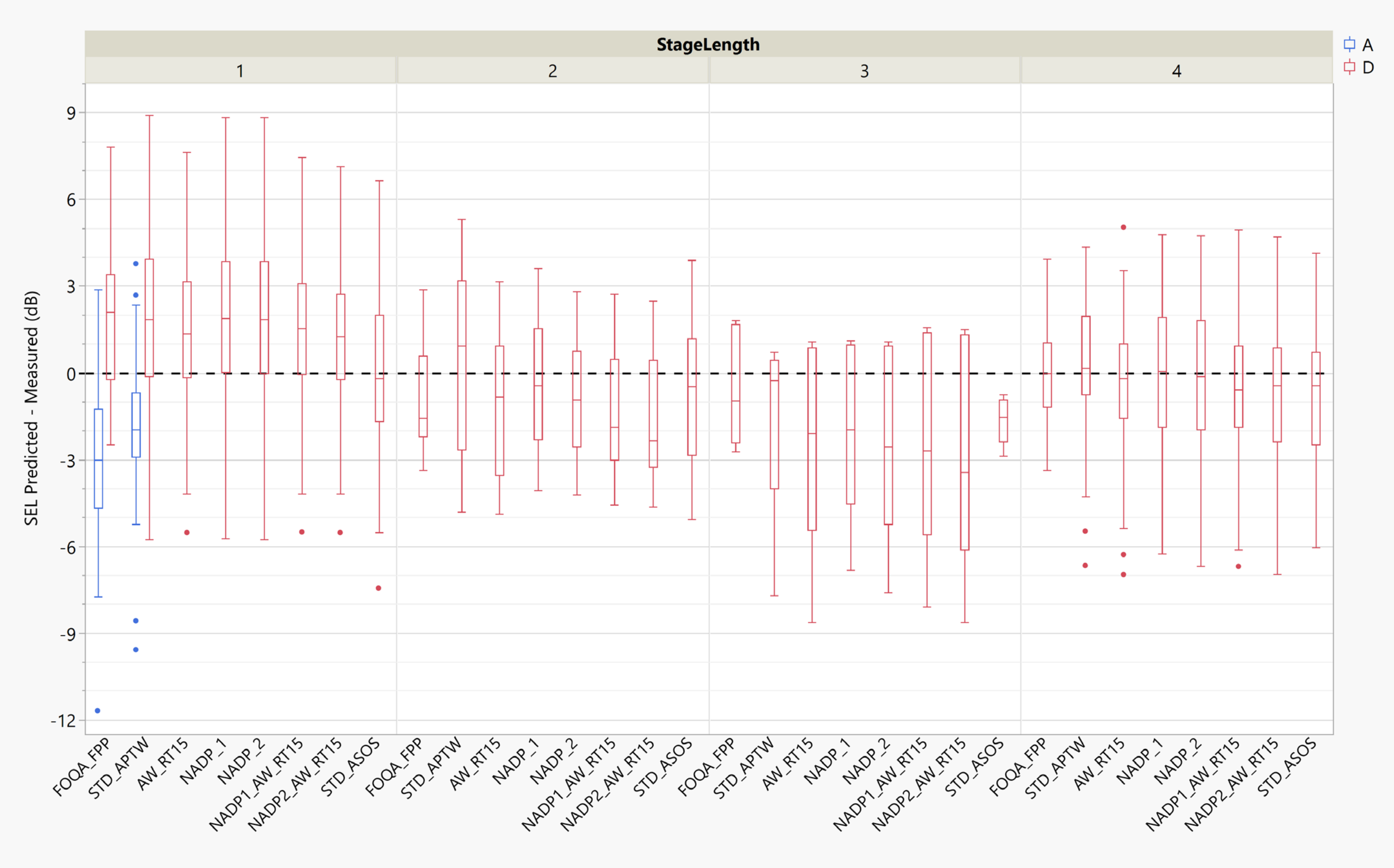

Figure 15. Predicted − measured sound exposure level (SEL) (dB) by stage length for all noise events. A, arrival; D, departure. _APTW – profile with airport weather. _ASOS – Profile with automated surface observing system weather. _AW_RT15 – Alternate Weight Reduced Thrust 15% . NADP – Noise Abatement Departure Procedure (1 or 2). FOQA_FPP – Flight Operations Quality Assurance Fixed Point Profile.

Noise data processing for SEA

Noise monitoring data for SEA were available as time history data consisting of 1-second L_{eq} values for July to December 2019, as well as SEL measurements of noise events for the entire year. The locations of noise monitors around the SEA airport are shown in Figure 16, and the FOQA flight tracks for operations at SEA for 2019 are shown in Figure 17.

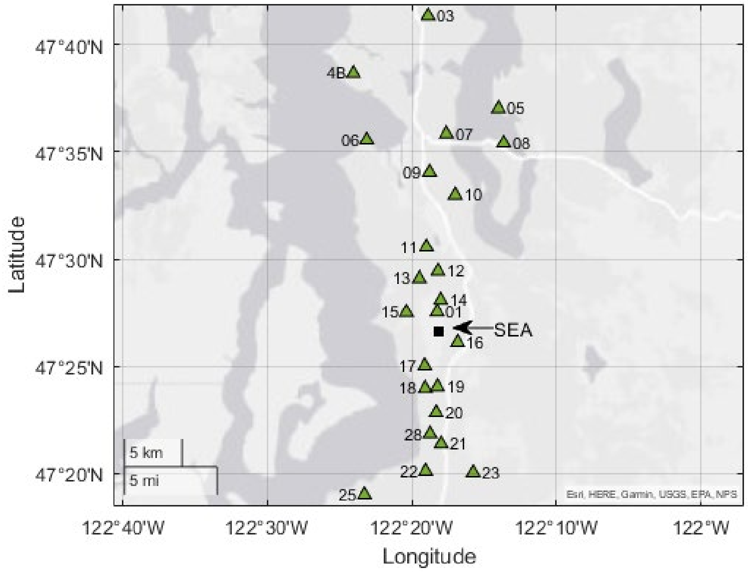

Figure 16. Locations of noise monitors around Seattle-Tacoma International Airport (SEA).

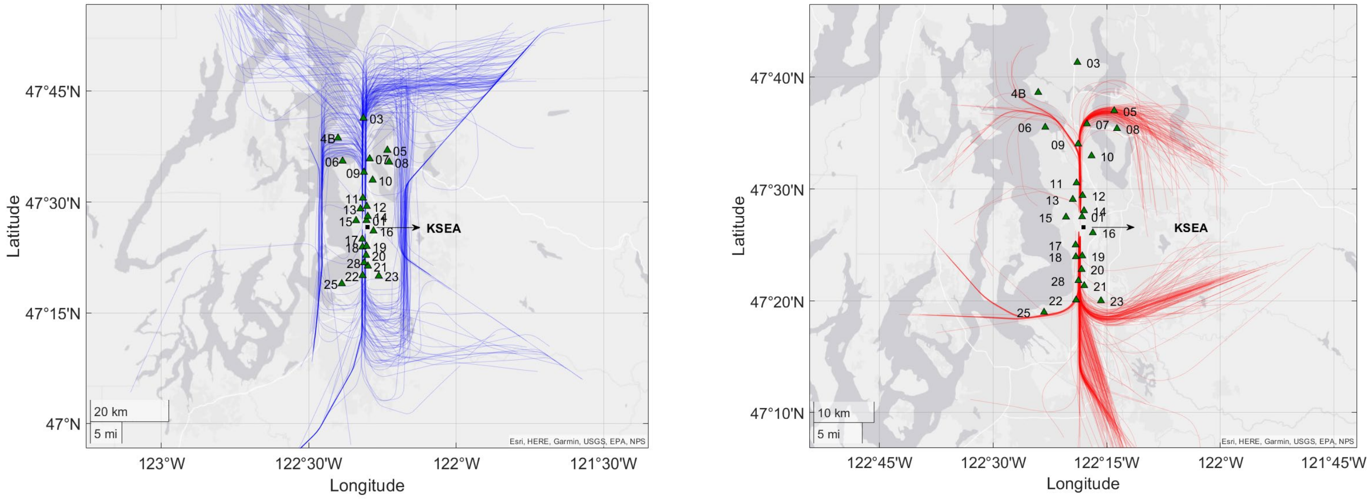

Figure 17. Modeled flight operational quality assurance (FOQA) arrival (left) and departure (right) tracks for Seattle-Tacoma International Airport (SEA).

To process the noise time history data for SEA, a dashboard was created that merged the FOQA and noise monitoring data. The developed dashboard enables the user to line up the FOQA flights with noise monitoring data to capture noise events by calculating the SEL, L_{max}, and background sound levels (L_{90}). The dashboard allows the user to visualize the 1-second L_{eq} values captured by noise monitors closest to the flight of interest. A user can manually identify a noise event and capture and export the SEL, L_{max}, and L_{90} values at the closest point between the flight and noise monitor. A snapshot of the dashboard is shown in Figure 18. In it, an arrival flight's noise event at SEA Monitor 12 (topmost in red) is captured. Presently, a total of 76 departure and 87 arrival FOQA operations have been correlated with noise data, resulting in 113 arrival and 198 departure noise events, respectively. After matching SEA-provided SEL noise events with FOQA data for the first 6 months of 2019, an additional 33 departure and 6 arrival noise events were identified. For SEA, flights with ambient wind speeds greater than 10 knots and nonzero precipitation were excluded prior to modeling in AEDT.


SEA Flights | ASCENT62 | v12

Select A Flight

a157	8	A319-100	A319-100 CFM56-5A	0	8	99999
a158	8	A330-300	A330-300 PW4000-100	11	5	99999
d159	8	A319-100	A319-100 CFM56-5A	9	18	99999
a160	8	A330-300	A330-300 PW4000-100	17	5	99999
a161	8	757-300	757-300 PW2000	4	6	99999
d162	8	717-200	717-200 BR715	NaN	NaN	NaN
d163	8	717-200	717-200 BR715	3	7	4800
d164	8	737-800	737-800 CFM56-7	5	9	99999

Time Control
Interval: 19 (sec)
Display Mode: External

Plot Options
Plot Size: 195 (pixels)
Plot Order By: Name

Plot Scale
Plot Scale: Local
Ordinate Minimum: 40 (dB)
Ordinate Maximum: 90 (dB)

Georgia Institute of Technology

Figure 18. Developed dashboard to capture event sound exposure level (SEL) and maximum, A-weighted sound level (L_{max}) from Seattle-Tacoma International Airport (SEA) noise time history data

Further processing of SEA noise results is currently ongoing to identify good quality data points by conducting outlier analysis. These results will be published in the following reports. Likewise, noise data from Minneapolis–Saint Paul International Airport (MSP) are under analysis and will be presented in a later report. Additional FOQA data and noise for 2021 will also be processed in future work.

AEDT is designed to be accurate on average while modeling the sound exposure of operations over a long duration at a place of interest. The present preliminary results confirm that fact and show that AEDT has a median error of between 0 and 3 dB over hundreds of flights and noise events across different monitoring locations at SFO. Although these results are important in validating AEDT, it is important to recognize the limitations of the results presented here. This study reports results from one airport, SFO, with its varied geography and climate, for the year 2019, while matching FOQA flight data to airport noise monitoring SEL measurements. While the authors have taken sufficient care in selecting noise events that meet stringent quality criteria to compare AEDT predictions with real-world operations, detailed noise time-histories were not available for the year under consideration. All acceptable arrival noise events at SFO were captured by just one monitor, potentially incorporating errors due to location and background levels that cannot be determined. For the next year of the project, some of these limitations will be addressed. Results from SEA and MSP are being processed for multiple years, which include noise time history data to improve the quality of data matching and comparison. This should provide sufficient results to generate confidence in AEDT's noise model for different weather and geographic conditions and for varied operations.

Milestones

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, and analyzed over 616 noise events (437 departures and 179 arrivals) to generate preliminary validation results.
- Completed outlier analysis to quality check flight-noise event results and shortlisted a total of 193 high-confidence noise events to complete SFO validation study for the year 2019.
- Presented SFO results at ASCENT spring and fall meetings in 2023.
- Analysis for 2019 noise validation data at two additional airports, SEA and MSP, is progressing.
- Coordinated with the PSU team to provide AEDT performance data required for tasks relevant to high-fidelity weather modeling.

Publications

Willitt, A., Bendarkar, M. V., Bhanpato, J., Kirby, M., Abelezele, S., & Mavris, D. N. (2024, Jan). Preliminary AEDT Noise Model Validation using Real-World Data. AIAA SCITECH 2024 Forum (ACCEPTED). Orlando, FL, January 2024.

Outreach Efforts

Held biweekly calls with the FAA, the Volpe Center, and Airborne Tactical Advantage Company (ATAC), and participated in biennial ASCENT meetings.

Awards

None.

Student Involvement

Georgia Tech

Graduate research assistants: Amber Willitt and Sabastian Abelezele completed the AEDT noise modeling and data analysis for San Fransisco (SFO) 2019 dataset. Sonal Mehta and Humfrey Kimanya worked on noise modeling and data processing for Seattle (SEA) 2019 dataset.

Plans for Next Period

Georgia Tech

- Complete noise data analysis for SEA and MSP airports for the years 2019 and 2021.
- 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.
- Collaborate with PSU to complete analysis of the impact of high-fidelity weather on noise predictions and measurement.

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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 our industrial partner Spire Global (http://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. 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 (e.g., 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. PSU is also investigating the influence of AEDT's atmospheric absorption and acoustic impedance adjustments in noise calculations if they were a function of high-fidelity weather. The ultimate goal is to suggest enhancements to AEDT that will enhance the predictive capability of AEDT's noise calculations with respect to real-world measurement data.

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 known to rarely be homogeneous, the impact of meteorological inhomogeneity on AEDT's noise calculations must be investigated to determine whether it substantially affects 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 flights departing from SFO and Washington Dulles International Airport (IAD). 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. Last year's work (Sparrow et al., 2022) demonstrated confidence in the in-house ray-tracing code by comparing in-house predictions with AEDT noise results for a Boeing 737-800 flight departing from SFO. For this year's work, the in-house ray-tracing code is being used to incorporate meteorological inhomogeneity in noise predictions and assess if it would be sufficient to rely on an appropriate average based on the layered (inhomogeneous) meteorological profiles when predicting noise levels on the ground. In parallel, PSU has continued the efforts to gain a deeper understanding of the AEDT noise calculations. Last year, PSU assessed the impact of high-fidelity weather on AEDT's acoustic impedance adjustment. This year's focus has been to understand the impact of high-fidelity weather on AEDT's atmospheric absorption adjustment.

Aircraft trajectory and locations of noise monitors

The Georgia Tech team has provided the flight tracking data for a departing Boeing 737-800 from SFO (anonymized flight ID: GT786D). Figure 19 shows the aircraft track associated with the flight and a color scale showing flight altitude above 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 SFO.

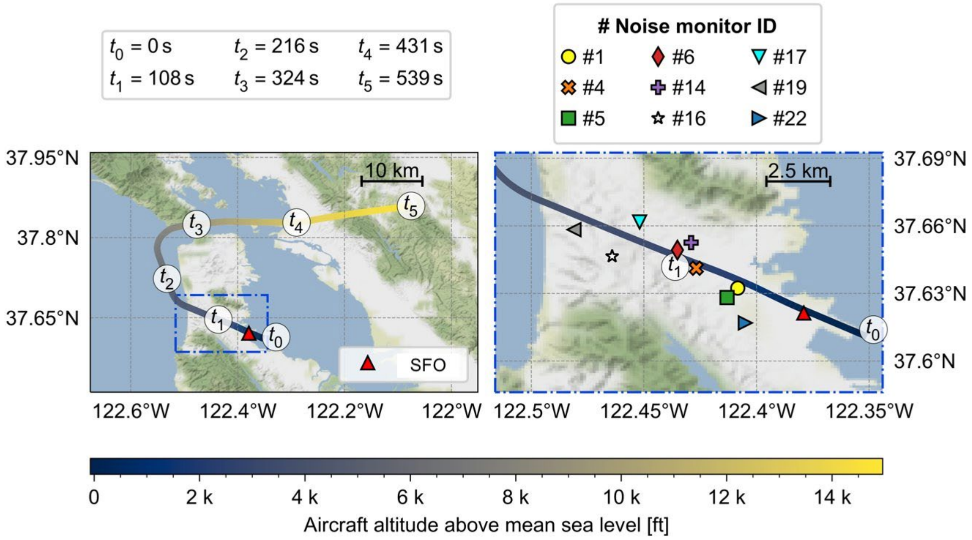

Figure 19. Aircraft trajectory and locations of noise monitors around San Francisco International airport (SFO) (anonymized flight ID: GT786D).

The noise monitor data available for this flight do not include the time history of the received noise but only the L_{max} (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 (Spire Global data vs AEDT's default annual airport weather)

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 20 shows the relevant temperature and specific humidity profiles. In Figure 20, the inhomogeneous meteorological profiles obtained near SFO from the Spire Global data are shown with a black line. As indicated in Figure 19, 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 20). Finally, the airport weather data for SFO, as given in AEDT, are shown with a dashed red line in Figure 20. 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 20 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 in Figure 20) satisfactorily improves the noise predictions (compared with annual average weather), this change in AEDT would be easier to implement. To investigate this possibility, the PSU team first set out to try to mimic AEDT's noise model by modifying a general-purpose acoustic ray-tracing code developed in-house. Last year's efforts by PSU successfully validated the in-house code. This year's work shows progress toward assessing the use of averages based on the high-fidelity weather data as an input to AEDT noise model instead of using ground-based weather measurements.

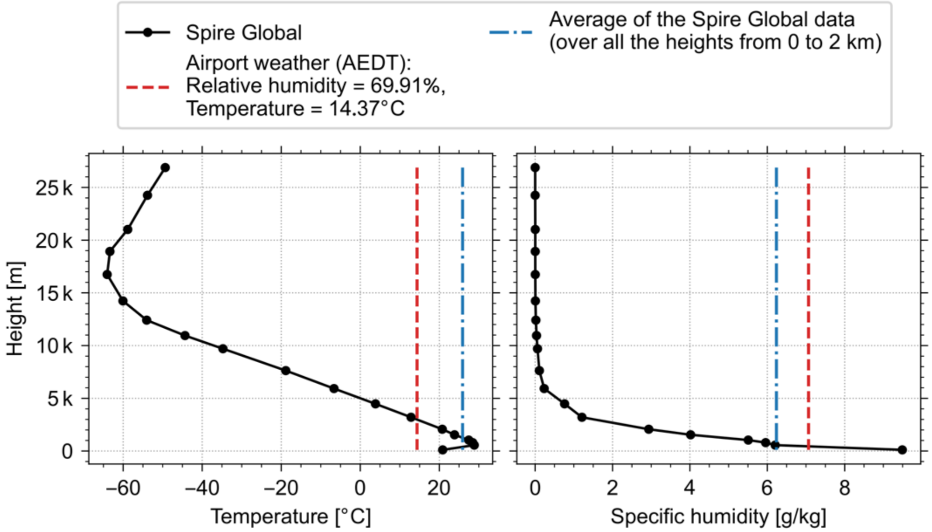

Figure 20. Comparison of the temperature and specific humidity profiles from AEDT and Spire Global data for flight GT786-D. AEDT, Aviation Environmental Design Tool.

Overview of PSU's in-house noise calculations and an attempt to include meteorological inhomogeneity

PSU's validated in-house code includes thrust-dependent source levels based on 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 from the NPD data 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 locations of the noise monitors. Atmospheric absorption is then applied according to SAE-ARP-5534 (SAE International, 2013). Because the goal is to be consistent with AEDT, some capabilities of PSU's in-house code had to be turned off to match AEDT's results. These include (a) explicitly accounting for moving source effects (Doppler shift and convective amplification); (b) a provision to include the effect of ground impedance; and (c) the ability to use a user-specified aircraft directivity information. Instead, to be consistent with AEDT, the PSU team used the lateral attenuation adjustment, as defined in the AEDT 3d technical manual (Lee, 2021). The lateral attenuation adjustment accounts for ground reflection, refraction, airplane shielding, and engine installation effects. As a first step toward including meteorological inhomogeneity in noise calculations, it makes sense to focus on changing (and potentially improving) the atmospheric absorption used in the noise calculations. While doing this, noise calculations can still rely on assuming straight rays (no refraction), as in AEDT, and use the lateral attenuation adjustment to account for refraction.

Preliminary results showing two ways of including absorption in noise calculations using the Spire Global data

Using the inhomogeneous Spire Global data, two new ways of including absorption in noise calculations are considered. The first case (Case 1) relies on an average of the Spire Global data over all heights from 0 to 2 km. The second case (Case 2) utilizes the layered (inhomogeneous) Spire Global data for calculating the absorption. With noise predictions based on the airport weather as a reference, Figure 21 shows the differences in noise predictions across multiple monitors for both cases of absorption. For all the monitors, the predicted SEL and $L_{\max}$ are always lower when using the Spire Global data rather than the annual average airport weather as given in AEDT. The difference in noise predictions obtained using an average of the Spire Global data (Case 1) instead of the layered profile (Case 2) seems to be negligible across all monitors for this flight. From Figure 21, it is evident that calculating absorption based on the Spire Global data (or an alternative source that provides relevant inhomogeneous meteorological profiles) clearly changes the noise predictions by about 1 to 1.5 dB for this flight. To arrive at a statistically significant conclusion, PSU (in collaboration with Georgia Tech) is currently looking at more than 100 noise events that occurred at SFO for the next year's work. In order to generalize the results and conclusions, the PSU team in collaboration with Georgia Tech is also looking at events from other airports.

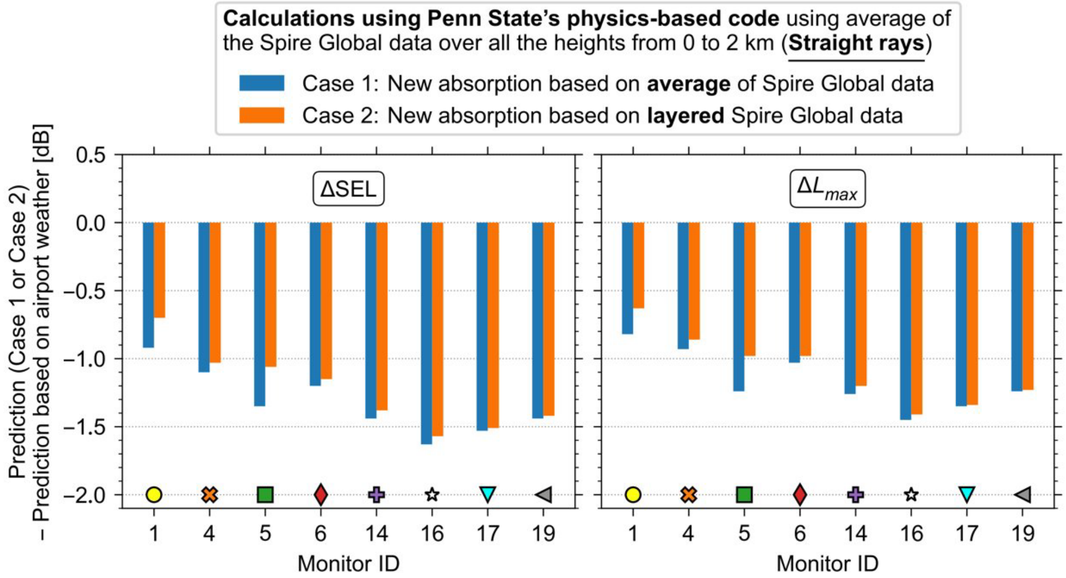

Figure 21. Difference in noise prediction when using new absorption based on Spire Global data instead of using the airport weather. SEL, sound exposure level; L_{max}, maximum A-weighted sound level.

Analyzing a noise event from IAD (in collaboration with Metropolitan Washington Airports Authority)
Until last year, PSU's in-house noise calculations have dealt only with a Boeing 737-800 departing from SFO. To have more confidence in PSU's in-house calculations, this year the team looked at a departing A319-100 aircraft from IAD (aircraft tracking data and AEDT performance outputs provided by Georgia Tech). Figure 22 shows the aircraft track associated with the flight and a color scale showing flight altitude above the mean sea level. The red triangle in Figure 22 shows the location of IAD, and the numbers shown in black are the noise monitors around the airport.

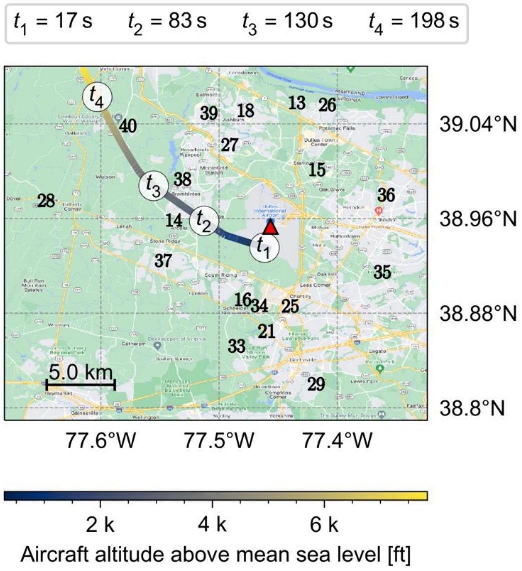

Figure 22. Aircraft trajectory and locations of noise monitors around Washington Dulles International Airport (IAD) (anonymized flight ID: GT-13D).

The Georgia Tech team ran an AEDT study with the FOQA data by using the fixed-point procedural profile and airport weather to provide noise predictions at the noise monitor locations shown in Figure 22. These results were compared with the noise predictions obtained with PSU's in-house code, assuming homogeneous weather as in AEDT (for IAD). Table 5 shows the difference between the in-house noise predictions and the AEDT noise predictions for the maximum A-weighted sound pressure level (L_{max}) and the A-weighted SEL for the two monitors closest to the aircraft ground track (Monitors 14 and 38). Reassuringly, the noise predictions using PSU's in-house code, as modified to match AEDT, closely matched AEDT's prediction. 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 small differences in noise predictions in Table 5.

Table 5. Difference between the in-house noise predictions (assuming AEDT-like weather) and AEDT's noise predictions for two monitors (closest to aircraft track) around Washington Dulles International Airport (IAD).

	Monitor ID	
	14	**38**
Δ L_{max} (dBA)	−0.35	−0.32
Δ SEL (dBA)	0.21	1.02

AEDT, Aviation Environmental Design Tool; SEL, sound exposure level; L_{max}, maximum A-weighted sound level.

Comparison of meteorological conditions (ERA5 data vs AEDT's default annual airport weather at IAD)

To maintain anonymity of the flight, only the date of the flight is known to PSU, not the exact time of the flight. To deal with this restriction, PSU downloaded meteorological reanalysis data ERA5 (Copernicus Climate Change Service, 2017) provided by the European Centre for Medium-Range Weather Forecasts for the whole day of the flight. ERA5 meteorological data are available for every hour of the day. Figure 23 shows 24 temperature and humidity profiles for each hour of the day of the flight, using colors ranging from yellow-green-dark blue. The annual average airport weather data for IAD, as given in AEDT, are shown with a dashed red line in Figure 23.

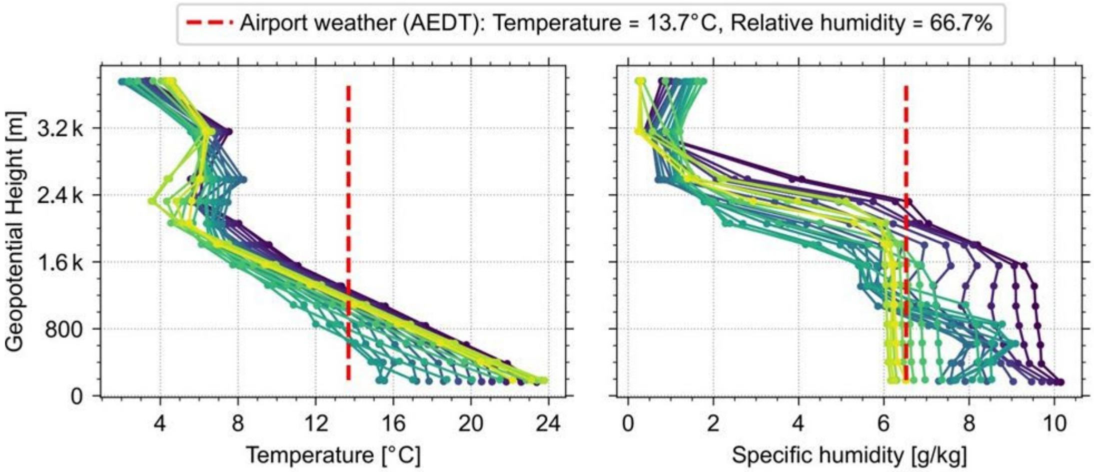

Figure 23. Comparison of Aviation Environmental Design Tool (AEDT) airport weather with 24 hourly profiles obtained using ERA5 data.

Noise predictions for Monitor 38 based on average meteorological conditions over all heights from 0 to 2 km

As shown in Figure 23, 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 yellow/blue/green lines for the hour closest to the noise event would be the best possible input for noise calculations. Because the exact time of the flight/noise event is not known, PSU conducted 24 numerical experiments (representing each hour of the day) using the validated in-house code. For these experiments, average meteorological conditions over all heights from 0 to 2 km were used as inputs. The meteorological averages and the corresponding results have been summarized and shown in

Table 6. The results shown in Table 6 are only for Monitor 38 (shown in Figure 22). Using AEDT's average annual weather (shown by a dashed red line in Figure 23) with PSU's in-house code, the SEL and L_{max} predictions are 71.2 and 57.5 dB, respectively. From Table 6, it is evident that the spread of the L_{max} and SEL predictions over 24 hours is within 0.3 dB of the noise predictions obtained using AEDT-like homogeneous conditions. This is due to a coincidence that the AEDT airport weather conditions are similar to the averages obtained using the ERA5 data. Please note that this contrasts with the results shown previously for the flight from SFO. For that flight, utilizing average conditions based on high-fidelity meteorological data led to considerable differences in noise predictions compared to the predictions based on AEDT's weather. This reiterates the importance of looking at different airports and times of the year before drawing a generalized conclusion about suggesting improvements to AEDT's absorption calculations.

Table 6. Average meteorological conditions for each hour of the day of flight and corresponding noise predictions.

Hour [GMT]	Average Temperature [˚ C]	Average Humidity [g/kg]	L_{max} [dB]	SEL [dB]
0	16.5	9.5	57.2	70.8
⋮	⋮	⋮	⋮	⋮
6	14.6	7.3	57.4	71.1
⋮	⋮	⋮	⋮	⋮
12	12.1	7	57.7	71.4
⋮	⋮	⋮	⋮	⋮
18	14.6	6.6	57.3	71.0
⋮	⋮	⋮	⋮	⋮
Minimum	12 ˚ C	6.1 g/kg	57.1 dB	70.8 dB
Maximum	16.5 ˚ C	9.5 g/kg	57.7 dB	71.5 dB

GMT, Greenwich Mean Time; L_{max}, maximum A-weighted sound level; SEL, sound exposure level.

Understanding AEDT's acoustic impedance and atmospheric absorption adjustments

In parallel with the previously mentioned work with the PSU-developed physics-based code, the research team also wanted to determine what parts of AEDT would be most affected by the introduction of high-fidelity weather data. The team quickly realized that both the acoustic impedance adjustment and atmospheric absorption adjustment affect *all* contour calculations in AEDT, and these adjustments are dependent on the meteorological values input to AEDT. After some false starts, the team carefully examined the acoustic impedance adjustment for the SFO cases previously mentioned. As can be seen from Figure 24, it became clear that the acoustic impedance adjustment only affected the overall noise calculations by 0.1 or 0.2 dB for aircraft operating close to the airport, when involved in takeoff or landing operations. The vertical axis of Figure 24 corresponds to the lowest 2 km above the ground. The acoustic impedance adjustment can be larger for higher altitudes and distances further from the airport, but this is not AEDT's primary function. In summary, acoustic impedance adjustment is not consequentially affected by the meteorological input values.

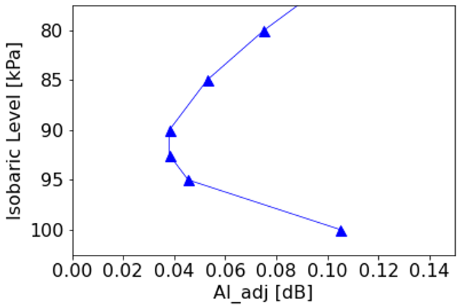

Figure 24. Acoustic impedance adjustment (AI_{adj}) directly above San Francisco International Airport (SFO). The vertical axis corresponds to the first 2 km of altitude above the ground.

On the other hand, the atmospheric absorption adjustment is a function of humidity, unlike that of the acoustic impedance adjustment. An example humidity profile is given in Figure 25, where again the vertical axis corresponds to the lowest 2 km of the atmosphere; note the strong dependence on humidity with height. When calculating the atmospheric absorption adjustment (see the AEDT Technical Manual) using such a varying humidity, the atmospheric absorption can change substantially with height. An example plot showing atmospheric absorption adjustment versus NPD distances for an SFO departure event is given in Figure 26, and a similar plot for an SFO arrival event is shown in Figure 27. The circles (blue) give the atmospheric absorption adjustment using surface weather values, and the triangles (red) give the adjustment using meteorological values averaged over the lowest 2 km. The difference between the two curves is on the order of 1 to 2 dB, depending on the NPD distance. Hence, the atmospheric absorption coefficient is substantially affected by the humidity profile. It is interesting to see that the level differences in Figure 26 and Figure 27between surface weather values and the values averaged over the lowest 2 km are on the same order as the level differences (bar lengths) seen in Figure 21 when comparing the PSU physics-based model using homogeneous (AEDT default) weather to the cases of either layered or average weather profiles. Therefore, there are some reasons to believe that including humidity profiles in the atmospheric absorption adjustment calculation could help AEDT predict noise levels more accurately. This should be investigated thoroughly.

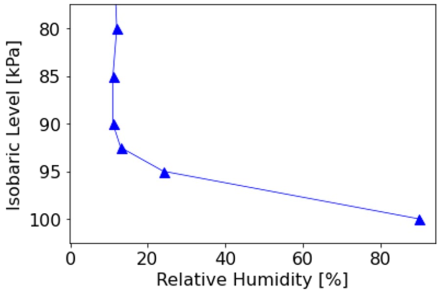

Figure 25. Example relative humidity profile. The vertical axis corresponds to the first 2 km of altitude above the ground.

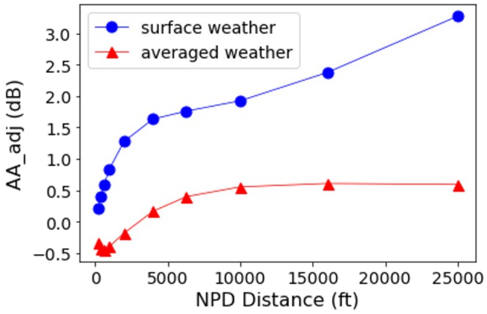

Figure 26. Atmospheric absorption adjustment (AA$_{adj}$) for an example departure event. NPD, noise-power-distance.

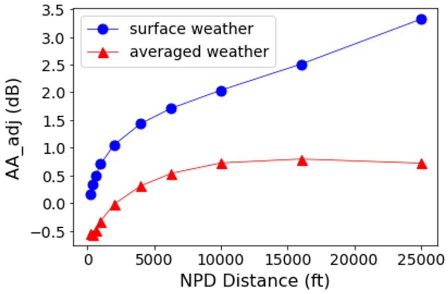

Figure 27. Atmospheric absorption adjustment (AA$_{adj}$) for an example arrival event. NPD, noise-power-distance.

Milestones

None.

Major Accomplishments

PSU accomplishments

- Using PSU's validated in-house ray-tracing code, two ways of including absorption based on inhomogeneous Spire Global data in noise calculations were examined. The noise predictions using atmospheric absorption based on a layered meteorological profile did not seem to differ significantly from predictions obtained using an average based on the inhomogeneous meteorological profile. Importantly, calculating absorption based on the Spire Global data did make a significant difference to predictions compared to using AEDT's annual airport weather (at least for the flight and day examined). As a contrast, noise predictions for a flight at a different airport – IAD (and on a different day) did not change significantly when using average meteorological conditions based on inhomogeneous meteorological conditions for the day of flight and AEDT's average annual airport weather.
- Concerning AEDT, it was determined that the atmospheric absorption adjustment is substantially affected by the humidity profile. This merits further research.
- The conclusions drawn based on PSU's preliminary results are consistent with the previous work by Plotkin et al. (2013) who had similar findings; i.e., using an appropriate average based on inhomogeneous meteorological profiles can improve noise predictions instead of relying on homogeneous annual average weather.

Publications

Emma Shaw, "Using high-fidelity weather data to improve impedance and absorption adjustment values in airport noise level predictions," M.S. Thesis (Graduate Program in Acoustics, The Pennsylvania State University, 2023). This reference is open access and available online at https://etda.libraries.psu.edu/catalog/19976eas6228 .

Outreach Efforts

Attended biweekly calls with the FAA and Georgia Tech, and participated in semiannual ASCENT meetings.

Awards

None.

Student Involvement

PSU graduate research assistants: Harshal Patankar and Emma Shaw.
Harshal Patankar worked on PSU's physics-based in-house noise calculations and analyzing real-world aircraft noise events near SFO and IAD using high-fidelity weather (obtained from Spire Global and ERA5). Emma Shaw worked on examining the impact of high-fidelity weather (specifically the humidity profile) on AEDT's atmospheric absorption adjustment.

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 for a larger number (>100) of events at SFO and other airports spread throughout a year to cover all seasons.
- 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 (Sparrow et al., 2021).

Special Acknowledgments

The contributions to ASCENT Project 62 by industrial partners Spire Global and Metropolitan Washington Airports Authority were incredibly important for this project. We gratefully acknowledge their essential and exemplary support to the PSU research efforts described here.

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