Project 053 Validation of Low Exposure Noise Modeling by Open-Source Data Management and Visualization Systems Integrated with AEDT

Stanford University

Project Lead Investigator

Juan J. Alonso
Vance D. and Arlene C. Coffman Professor
James and Anna Marie Spilker Chair of Aeronautics & Astronautics
Department of Aeronautics & Astronautics
Stanford University
Stanford, CA 94305
Phone: (650) 723-9954
E-mail: jjalonso@stanford.edu

University Participants

Stanford University

- P.I.(s): Juan J. Alonso, Professor
- FAA Award Number: 13-C-AJFE-SU-022
- Period of Performance: October 1, 2023, to September 30, 2024
- Task(s):
    1. Complete prototype of Metroplex Overflight Noise Analysis (MONA), including integration of the Aviation Environmental Design Tool (AEDT). Completed.
    2. Validation and verification of AEDT noise predictions in day-night average sound level (DNL) 55-65 dB areas. Completed study (for arrivals into San Francisco International Airport [SFO] Runways 28L/R only) and submitted journal paper, which was published in March 2024.
    3. Data science formats and scientific computing for large-scale airspace analyses. Completed.
    4. Viable alternative approach routes into the San Francisco Bay Area metroplex. Pending/de-scoped.

Project Funding Level

A hiatus in funding meant that no additional funds were received for the work during this reporting period. Although the work of preparing a journal publication continued, no students were funded during the period of performance. The project is expected to restart on January 1, 2025, to complete the study with departure operations from SFO and preparations for conducting similar studies at other airports or different time period at SFO. Even though funding was not received for this period of performance, both Mr. Thomas Rindfleisch and Mr. Donald Jackson contributed a significant portion of their time (approximately 30% full time equivalent [FTE] for Jackson and 50% FTE for Rindfleisch), uncompensated, to the project. In addition, some contractor costs (a small amount this past year) for the continued development of the MONA project visualization website and some minor equipment purchases (and installation costs) were also used to generate cost share for this project. Up until the end of the period of performance for this report, a total of more than $1.85M of cost share has already been generated and accounted for.

Investigation Team

The investigation team is made up of the faculty, graduate and undergraduate students, and collaborators listed below with their respective areas of expertise/areas of contribution:

1. Juan J. Alonso (P.I., Stanford Aeronautics & Astronautics): Overall responsibility for the project and its technical and administrative elements.

2. Brian Munguía (Graduate Student, Stanford Aeronautics & Astronautics): AEDT, cloud-based AEDT study execution, AEDT debugging; departures study development and initial debugging. During the period of performance (October 1, 2023, through September 30, 2024), Mr. Munguía performed a small number of tasks in support of the journal paper submission.
3. Donald Jackson (Collaborator, software developer): Overall MONA project infrastructure (i.e., servers, databases, hardware/software monitoring), geographic information system (GIS), web-based visualization deployment, technical guidance. During the current period of performance, Mr. Jackson continued to maintain our infrastructure database and to ingest and curate the noise data.
4. Thomas Rindfleisch (Co-P.I., Sr. Research Scientist, Emeritus, Stanford University): Noise monitoring and filtering, aircraft trajectory collection/processing, visualization, data analysis. During the period of performance, Mr. Rindfleisch was instrumental in preparing all the data for our journal submission and generating the main manuscript in collaboration with Professor Alonso. October 1, 2023, through September 30, 2024.

Project Overview

The MONA project was started to provide real-time and objective data, analyses, and reports to key stakeholders and policy makers to mitigate the noise impacts of the deployment of new NextGen procedures. This system (a) collects and archives air traffic data using a network of antennae and Automatic Dependent Surveillance-Broadcast (ADS-B) receivers, (b) analyzes noise impacts using a variety of metrics, (c) visualizes resulting large-scale datasets, and (d) uses a network of sound-level monitors (SLMs) to validate and enhance the quality of noise predictions. The focus of this ASCENT project is to improve upon the noise predictions of MONA through tighter integration with AEDT. In particular, our work is focused on the following three tasks: (1) integrate and automate AEDT's noise analysis capabilities, (2) validate and verify (V&V) AEDT's noise predictions in DNL 55-65 dB areas, and (3) propose software engineering/architectural choices for future AEDT development to enhance usability in multiple workflows including application programming interface (API) formulation, visualization interfaces, resilient data acquisition and storage, and cloud computing.

The expected benefits of this project mirror the tasks mentioned above, including (a) ability to automate complex noise analyses in metroplexes so they are available in near-real time after the preceding 24-hr period, (b) a better understanding of the accuracy of AEDT's current noise models in high- (DNL >65 dB) and low-noise (DNL 55-65 dB) areas and the reasons for the discrepancies (if any) in existing predictions, and (c) recommendations to software developers on flexible architectures and APIs for AEDT so that the tool is more versatile and generally applicable. AEDT predictions are built around the policy context of an average annual day. The majority of the V&V results produced and shared by the MONA team had focused on a cumulative daily basis for which flight track data is directly collected. The project thus far has managed to automate the cloud-based analysis (using many parallel instances of AEDT) of *every flight into SFO for a period of an entire year (July 1, 2021, to June 30, 2022)* and therefore some of our results, included in the March 2024 journal publication (Rindfleisch et al., 2024), now contain DNL levels based on the flight operations collected through the MONA system. The focus of the work the MONA team has done so far is on arrivals at SFO with main attention paid to arrivals into Runways 28L/R. Having created the entire framework and having generated data for a full year of arrivals operations, the effort during this past year focused exclusively on creating, submitting, and providing reviews for a journal publication including all of our results to date. The final journal publication in the *Journal of the Acoustical Society of America* (JASA) was made available online and published in Volume 155, Issue 3 in March 2024. The full citation for the 2024 JASA paper, which includes all of our results to date is:

Rindfleisch, T. C., Alonso, J. J., Jackson, D. C., Munguia, B. C., & Bowman, N. W. (2024). A Large-Scale Validation Study of AEDT Noise Modeling for Aircraft Arrivals. *Journal of the Acoustical Society of America*, *155*(3). https://doi.org/10.1121/10.0025276

Background and Previous Accomplishments

The MONA project started approximately six years ago with the main objective of providing real-time and objective data, analyses, and reports to key stakeholders and policy makers to help in mitigating the noise impacts of the deployment of new NextGen procedures. Since then, the MONA team has put together and deployed a system that (a) collects, archives, and makes available air traffic data using a series of networked antennae and ADS-B receivers 24/7, (b) analyzes noise impacts using a variety of metrics (based on both a MONA-developed noise prediction tool and the noise prediction tools within AEDT), (c) visualizes resulting large-scale datasets in a simple, user-friendly fashion using both a bespoke website and Uber's® kepler.gl and deck.gl large-scale data visualization toolboxes, and (d) has deployed a small network of low-cost, Stanford University-owned, sound-level monitors scattered across the South Bay part of the San Francisco Bay Area and has included the data from the noise monitors deployed by SFO to cross-calibrate measurements by MONA and SFO monitors, collect noise measurements more widely geographically, and enhance noise predictions to describe exactly the actual noise levels experienced.

The longer-term objectives of the MONA project are to (a) ensure the validation and verification of all noise predictions provided (by AEDT or other tools) in both areas near the airport and in other areas further away from the airport, (b) achieve full automation of complex noise analyses in regions around airports in the United States, including AEDT-based noise predictions, (c) make all results web-accessible for in-depth interpretations of historical and proposed changes, (d) eventually study potential alternative traffic patterns in complex airspace to mitigate aviation environmental impacts, and (e) export the proven/validated MONA technology to other airport regions via open-source software/hardware.
The MONA system has matured considerably over the past few years to the point that a full-system prototype has now been operational for some time. In fact, for all arrival operations into SFO, the system is considered to be fully operational. To recall the main elements of the system, the MONA team has deployed a small network of ADS-B/multilateration (MLAT) antennae and has completed the software necessary to merge the data streams from all of these antennae including de-duplication of sightings, identification of aircraft equipment and routes flown, physical interpolation of data missing from the joint observations, and archiving (in appropriate database formats) of the information collected for successive analysis. Moreover, for arrival operations, considerable time and effort has been spent understanding the best ways to utilize AEDT (by understanding the methods to most accurately model aircraft trajectories, aircraft equipment, and aircraft noise) so that any comparisons between experimental data and the results obtained from AEDT may be affected as little as possible by confounding variables. In fact, the MONA team has spent time in using AEDT in multiple ways including the standard version of AEDT that is approved for regulatory use in the United States and an improved version that leverages higher-fidelity aircraft performance models (base of aircraft data [BADA] 4) and detailed descriptions of individual aircraft trajectories (using the so-called altitude and speed controls that result from the ADS-B data and its post-processing).

The MONA system has achieved a level of integration with the Federal Aviation Administration's (FAA) AEDT software that enables fully automatic processing of noise exposure at arbitrary receptor locations for arrival and departure routes into the San Francisco Bay Area airports. The JASA publication and this report include our published and most accurate and comprehensive assessment of the comparison between AEDT predictions and noise-monitoring stations created to date, with an entire year of flights observed at multiple locations. In total, more than 200,000 datapoints give statistical significance to the results that the MONA team has obtained, that are presented here, and were submitted for peer-reviewed publication.

Again, direct research efforts were halted during this past year of performance but work continued, as part of Task 2, to curate the simulation and experimental information for publication in an archival journal. This short yearly report focuses on a summary of the results contained in the2024 JASA paper for arrivals into SFO only. No report on the progress on other tasks is provided in this report, including our departures V&V work, as that work will restart at the beginning of 2025.

Task 2 - AEDT Noise Prediction Assessment in DNL 55-65 and DNL > 65 dB Areas

Stanford University

Our team has previously reported on the development of the MONA system, that data that it acquires, the information processing (both to prepare and post-process AEDT simulations and to filter and curate experimental noise data) that is necessary to V&V the predictions, and the preliminary observations from all the data collected and produced. Last year's report focused on the statistically significant characterization of the discrepancies between the measured noise at two different noise-monitoring stations and the predictions using AEDT in various ways with increasing levels of modeling fidelity. The reader is referred to last year's report for more details. By *statistically significant*, it is meant that the observations and conclusions are based on large amounts of data that are deemed to have converged probability

® Uber is a registered trademark of Uber Technologies, Inc., San Francisco, California.

distributions and statistical moments (e.g., expected value/mean and standard deviations). In other words, we do not attempt to draw conclusions about the predictive qualities of AEDT noise models based on 5 to 10 flights (as has been common in the literature) but that, rather, our focus is on large-enough numbers of observations: at least 10,000 flights/data points for the main aircraft types and over 200,000 flights, over a 12-month period, for our entire study.

Moreover, the actual data from which conclusions are drawn is highly curated to eliminate any noise events that are even slightly unlikely to be the result of aircraft overflights alone, and other situations where multiple aircraft may pass over a noise-monitoring station nearly simultaneously. This is to say that we feel confident that the data presented in this report (directly taken from the JASA paper) is of the highest quality possible. The data presented and associated conclusions/observations, with the limitation to SFO and to arrival operations, has been peer reviewed and approved for publication in JASA.

The remainder of this section is a summary of the key results included in the 2024 JASA paper. For more details, the reader is referred to the full journal article that can be found at https://pubs.aip.org/asa/jasa/article/155/3/1928/3270390/A-large-scale-validation-study-of-aircraft-noise.

Summary of Results from the 2024 JASA Paper

In the United States, the FAA's AEDT is approved to predict the impacts of aircraft noise and emissions. AEDT's critical role in regulatory compliance and evaluating the environmental impacts of aviation requires questioning the accuracy of its noise predictions. Previous studies suggest that AEDT's predictions may lack desired accuracy, especially in regions of relatively low noise (< DNL 55 dB). The journal paper reported on a large-scale study, using 200,000 flight trajectories paired with measured sound levels for arrivals to Runways 28L/28R at SFO, over 12 months. For each flight, two AEDT studies were run: (1) using the approved mode for regulatory filing and (2) using an advanced nonregulatory mode with exact aircraft trajectories. AEDT's per aircraft noise predictions were compared with curated measured sound levels at two locations. On average, AEDT underestimated LAmax[1] by 3.09 dB and sound exposure level (SEL) by 2.04 dB, combining the results from both AEDT noise-modeling modes. Discrepancies appear to result from limitations in the physical modeling of flight trajectories and noise generation, combined with input data uncertainties (i.e., aircraft weight, airspeed, thrust, and lift configuration) and atmospheric conditions. Further V&V investigation is required to ascertain the level of prediction accuracy in departure operations and, possibly, with upcoming improvements to the modeling strategy of terrain and ground effects.

The aims of the study in the 2024 JASA paper were fourfold:

1. To collect a very large, statistically significant set of data, pairing aircraft flight profiles with carefully curated sound level measurements over time and identifying intrinsic limitations in the physical measurements.
2. To select aircraft study cohorts that control, as much as possible, many of the flight variables involved while examining AEDT behaviors for a broad, real-world fleet mix.
3. To tease out statistically significant measures of AEDT metric prediction accuracy and analysis anomalies, aircraft-type by aircraft-type, to reveal internal computational strengths and weaknesses.
4. To provide recommendations for work needed to improve AEDT's noise prediction accuracy.

To model an aircraft flight arrival with AEDT, a detailed study file was created specifying all of the appropriate parameters, including calibrated airspeed, derived from ADS-B ground speed using the National Oceanic and Atmospheric Administration (NOAA) High-Resolution Rapid Refresh (HRRR) atmospheric data (Alexander et al., 2020). In the study, the AEDT's noise predictions were compared using two different modeling approaches:

1. AEDT regulatory mode (AEDT-R): Aircraft Noise and Performance Database (ANP)/BADA 3, with only ground-track positions specified; no altitude or airspeed controls are provided. This is the modeling approach required by the FAA for regulatory purposes.
2. AEDT-AE: BADA 4, with both altitude and airspeed controls specified for each ground-track position.

Our team attempted to use AEDT to the best of its predictive abilities, and for that reason, the FAA and Volpe Center experts were consulted to optimize the preparation of flight-profile data to fit AEDT modeling constraints (e.g., smoothing

[1] LAmax is a tool that uses aircraft performance modeling to estimate aircraft noise levels, and other factors such as fuel consumption, emissions, and air quality. LAmax stands for the highest or maximum sound level of an event.

flight profile parameters and limiting profile altitude or speed changes). User-defined flight modeling profiles were not attempted to be developed, although such efforts might result in a closer match between AEDT predictions and SLM measurements (Meister et al., 2023; NAS, 2018).

To validate the noise predictions of AEDT, we compare and analyze the AEDT-estimated noise metrics (using "trajectory-driven flight performance" modeling [FAA, 2021a]) and ground SLM measurements along each of the three chosen route segments. The AEDT-R results incorporate all aircraft in our fleet mix that have ANP/BADA 3 models, whereas AEDT-AE results are limited to the aircraft types in our fleet mix that have BADA 4 models (FAA, 2021b). The noise predictions for flights on final approach to Runways 28L and 28R are compared with recordings from the SFO monitor NMT-12 in Foster City, 0.4 miles line-of-sight distance from the flight paths. Predictions for approaches along the SERFR-DIRECT route are compared with recordings from one of our project monitors in Palo Alto, 0.9 miles line-of-sight distance from the flight path, at the SIDBY waypoint.

Table 1 summarizes the total number of flights successfully studied for each modeling approach and how various subsets of flights were discarded for failing quality and relevance criteria. The rows in Table 1 describe the results of our data screening. The input AEDT/SLM pairs represent all flight profiles for which a successful AEDT study was run with BADA 3 and/or BADA 4 modeling, and which were detected at the SLM associated with the column heading. These counts exclude flights intended to be modeled as BADA 4, but which AEDT downgraded to BADA 3 modeling. The "Number of pairs skipped as the GA [general aviation]" row is the count of those discarded as general aviation flights. The "pairs skipped for low GoF [goodness-of-fit]" is the count of pairs for which the SLM peak shape was suspect because it was distorted relative to an analytic model peak using our GoF metric (refer to the Appendix in the 2024 JASA paper for more details). The "pairs skipped for multiple PCA [points of closest approach]" is the count of pairs for which the SLM peak was suspect because the arrival time of the sound maximum at the PCA to the SLM could be attributed to more than one aircraft. The "pairs skipped for trajectory criteria" is the count of pairs that do not conform geometrically to the arrival flight path criteria (i.e., distance, elevation, altitude, speed, heading, etc.). Note also that all pairs are collected (flight and corresponding matched SLM peak) by SLM and then partitioned according to route information. Since the ADS-B data does not contain runway information, the first four rows of Table 1 are identical for SFO Runways 28L and 28R. After each aircraft trajectory is followed to the ground, we are able to identify the actual arrival runway and, therefore, rows 5-8 in Table 1 contain information for flights that arrived at either Runways 28L or 28R.

Table 1. Size of AEDT-R and AEDT-AE cohorts for each route segment.

Data volume statistics:	SFO Runway 28L	SFO Runway 28R	SIDBY SERFR-DIRECT
Number of input AEDT/SLM pairs	226 876	226 876	113 113
Number of pairs skipped as GA	4927	4927	2145
Number of pairs skipped for low GoF	55 861	55 861	70 130
Number of pairs skipped for multiple PCAs	9756	9756	525
Number of pairs skipped for trajectory criteria	58 282	105 988	14 020
Number of post-filter pairs	98 050	50 344	26 293
Number BADA 3 pairs	55 793	30 214	14 112
Number BADA 4 pairs	42 257	20 130	12 181

The 2024 JASA paper contains results with both the AEDT-R version (straight out of the box, the version approved for regulatory purposes) and using AEDT-AE (the version that utilizes better aircraft performance models and the possibility of using altitude and airspeed controls that, together with latitude/longitude measurements, can represent the actual trajectory flown by an aircraft exactly). AEDT-AE represents the aircraft performance model and its trajectory with significantly higher fidelity than what is possible in AEDT-R and, therefore, in this summary of the 2024 JASA paper, the results obtained with AEDT-AE are the focus. The reader is referred to the paper for details of the results obtained with AEDT-AE.

AEDT-AE Results

The statistical analysis of the pair-by-pair relations begun between the AEDT-AE LAmax estimates and the corresponding SLM measurements by showing a series of histogram plots, including all of the aircraft and trajectories simulated, and some highlights by aircraft type. Using BADA 4 data from final approaches to SFO Runway 28L (42,257 pairs including 14 ANP performance models), Figure 1 shows histograms of the AEDT-AE LAmax estimates (solid line) and of the SLM LAmax measurements (dotted line). As the histogram labels indicate, the average AEDT-AE LAmax level is 68.59 ± 1.52 dB and that measured by the SLM is 71.32 ± 2.15 dB—on average AEDT underestimates the LAmax value by 2.73 dB. Also, note that the profile of the predicted AEDT values has significant internal structure, indicated by the subpeaks, including one sidelobe at 70.95 dB, and inflection points in the non-Gaussian shape. No discrete subpeaks are present, however, as were prominent in the AEDT BADA 3 predictions (refer to the 2024 JASA paper). This reflects the more sophisticated physics modeled in AEDT BADA 4 and the spread in the trajectories actually flown that are considered in this analysis.

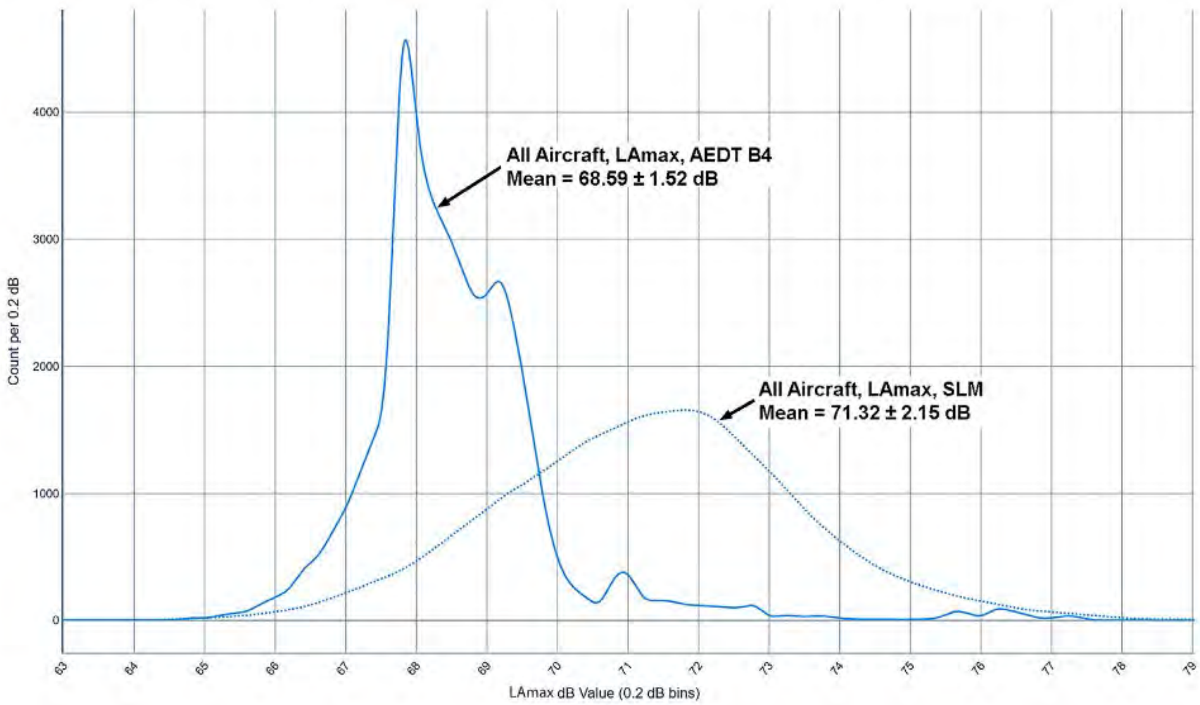

Figure 1. AEDT-AE, SFO NMT-12, Runway 28L. Distributions of predicted LAmax (solid line) and measured LAmax (dashed line) values.

This structure can be elaborated by overplotting histograms for various aircraft sub-cohorts modeled by particular ANP performance models as shown in Figure 2. To simplify the plot, only three major aircraft types are shown. One can see that the AEDT-AE calculations produce histogram profiles with quite varied shapes and that the differences in mean LAmax values between the AEDT-AE predictions and the SLM measurements differ significantly (see the green profile for ANP model 737-800 in particular). It is evident from this plot (and by extension for the entire cohort of aircraft types and ANP performance models) that there are important model-based differences between the estimates AEDT-AE makes and what the SLM measures. These are important in that for the most part the AEDT-AE predictions fall short of the SLM measurements—a result analogous to that seen for the AEDT-R BADA 3 analysis in the 2024 JASA paper.

The AEDT/SLM differences and their distributions can be illustrated by a performance model by computing the metric difference directly for each AEDT/SLM pair and then plotting the histogram of those differences. This comparison is illustrated in the histograms in Figure 3, both for the overall cohort and for a subset of individual ANP performance models for the most frequent types. These differences range from 2.08 dB for the A321-232 performance model to 3.44 dB for the 737-800 model, all with standard deviations ~2 dB (which result from the relatively broad SLM measurement distributions).

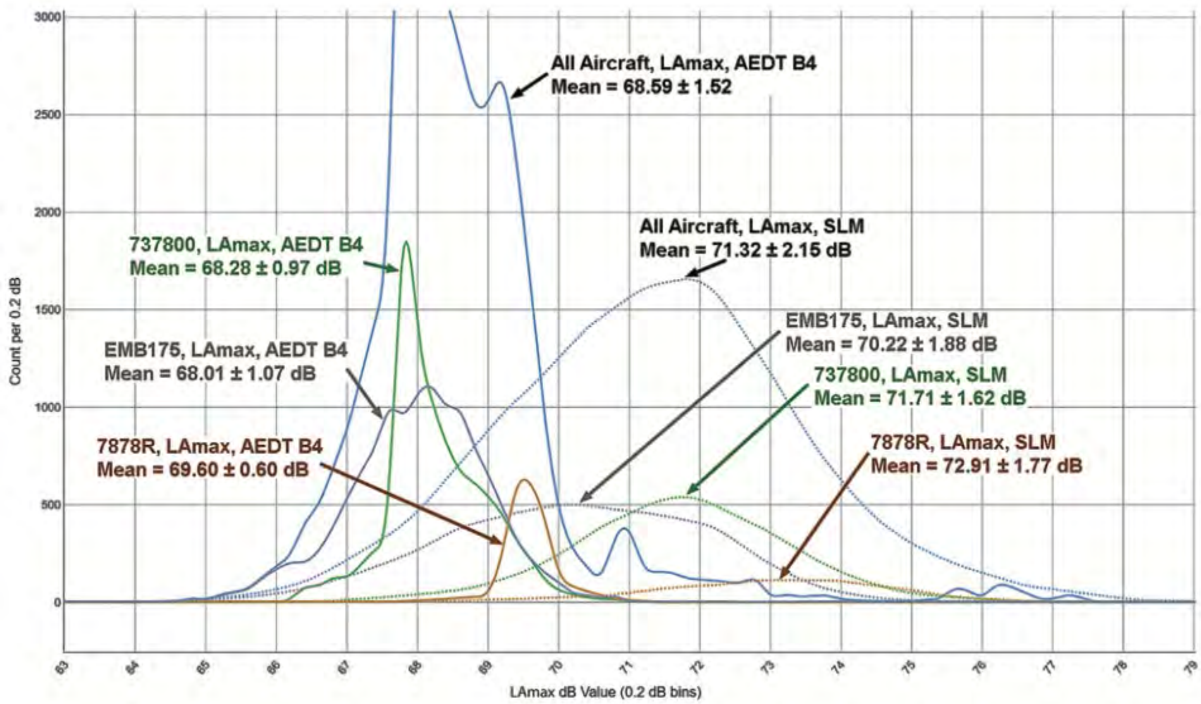

Figure 2. AEDT-AE, SFO NMT-12, Runway 28L. Distributions of predicted LAmax (solid line) and measured LAmax (dashed line) values for selected aircraft.

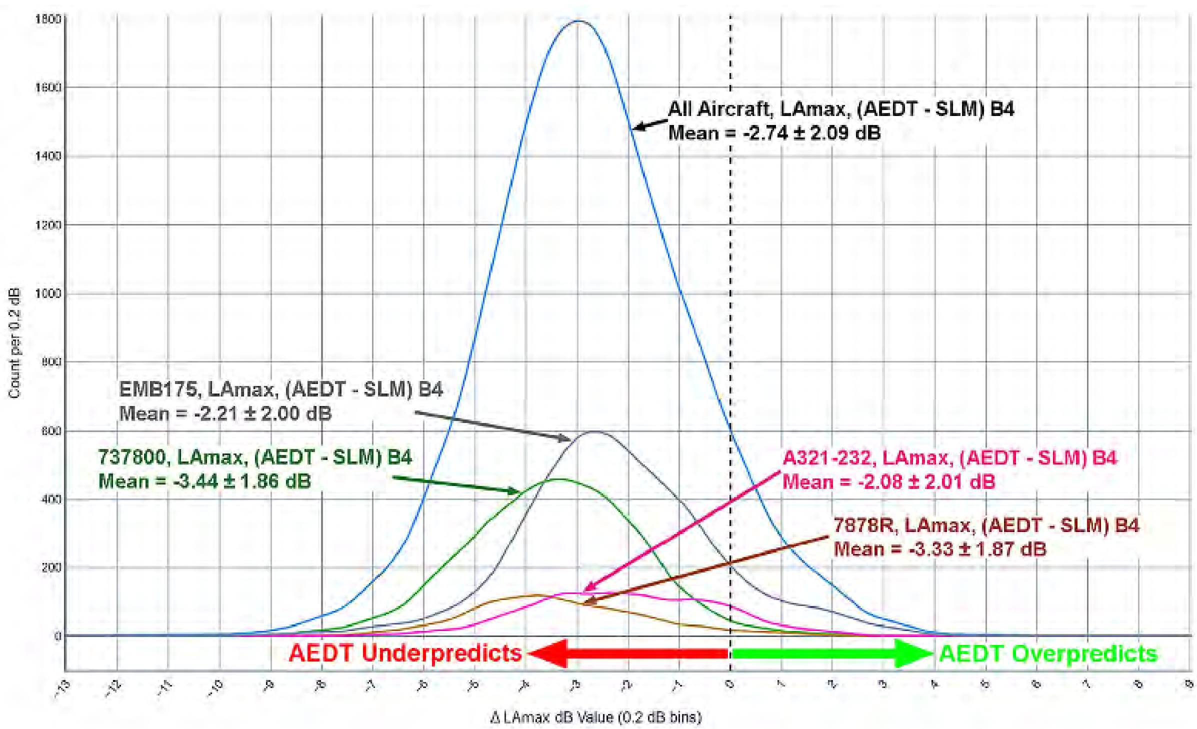

Figure 3. AEDT-AE, SFO NMT-12, Runway 28L. Distributions of LAmax differences (AEDT–SLM) for entire cohort and for selected ANP.

Based on the analyses illustrated in Figures 1, 2, and 3, the difference error statistics is computed for all 14 ANP performance models found in the aircraft cohort. Figure 4 shows an ordered plot of the error values and Table 2 shows the detailed sample flight counts, difference values, and standard deviations. The SEL metric data collected from AEDT-AE study runs and SLM measurements are analyzed with exactly the same approach used for LAmax; the results for the SFO Runway 28L approach are also shown in Figure 4 and Table 2.

As is evident in Figure 4, there are major differences in the accuracy of the AEDT-AE LAmax predictions. For example, the differences for “heavy” aircraft (ANP models 747-400 and 747-8) are relatively small, indicating that the corresponding models seem to be fairly accurate. For the other aircraft though, the accuracy of the AEDT-AE modeling appears to produce systematically low estimates, ranging from 1.6 dB to 3.9 dB. The overall LAmax error weighted by frequency counts is 2.74 dB.

The overall difference between AEDT-AE SEL predictions and SLM measurements for the SFO 28L approach is slightly less, 2.48 dB. On the other hand, the same basic observations about their variable nature and the inability of AEDT-AE to model sound metrics accurately for different ANP performance models apply.

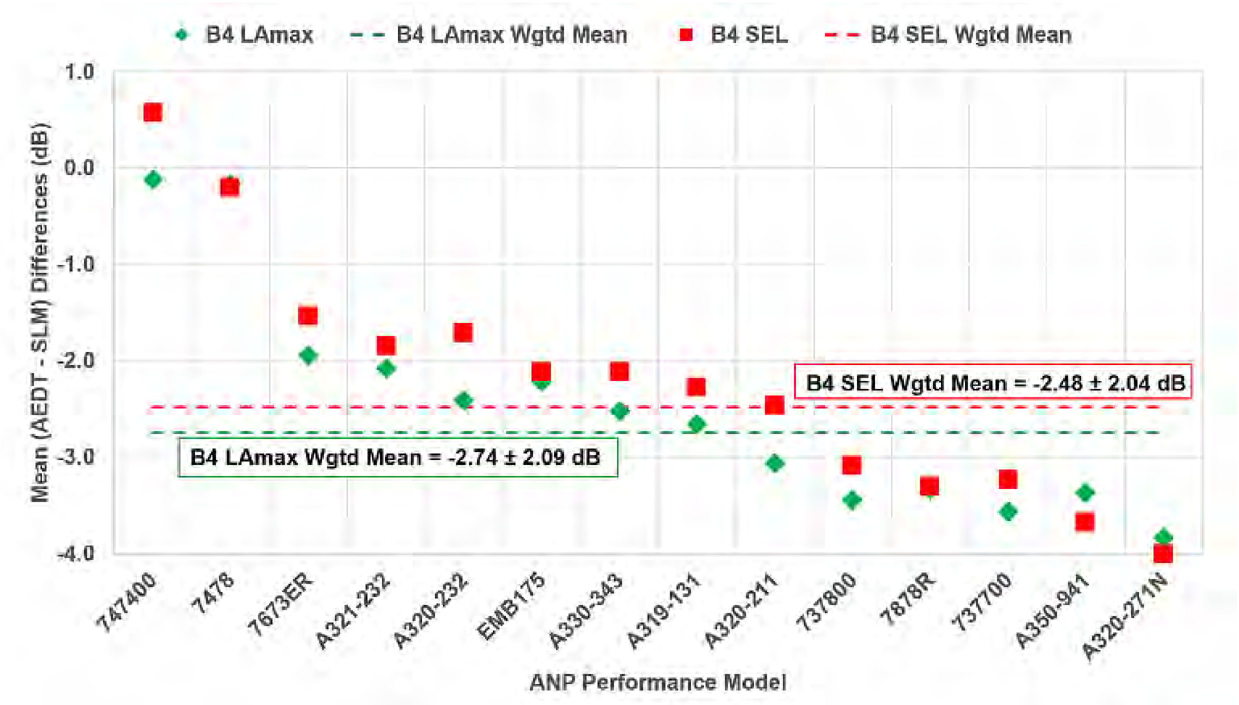

Figure 4. AEDT-AE, SFO NMT-12, Runway 28L. Mean LAmax and SEL differences (AEDT–SLM), by ANP model. The green diamonds for 7478 and 7878 R LAmax are hidden behind the corresponding red SEL squares.

Table 2. AEDT-AE, SFO NMT-12, Runway 28L. Mean and standard deviations of LAmax and SEL differences (AEDT – SLM), by ANP model.

ANP code	BADA code	Subcohort size	AEDT–SLM LAmax difference	AEDT–SLM SEL difference
ALL	All	42 257	−2.74 ± 2.09	−2.48 ± 2.04
737700	B737	2 685	−3.57 ± 1.78	−3.23 ± 1.66
737800	B738, B739	9 793	−3.44 ± 1.86	−3.09 ± 1.72
747400	B744	177	−0.11 ± 1.65	0.57 ± 1.55
7478	B748	304	−0.16 ± 1.35	−0.20 ± 1.30
7673ER	B763	1 212	−1.94 ± 2.06	−1.54 ± 1.96
7878R	B788, B789, B78X	2 408	−3.33 ± 1.87	−3.31 ± 1.77
A319-131	A319	2 251	−2.65 ± 2.22	−2.27 ± 2.12
A320-211	A320	2 072	−3.06 ± 1.83	−2.46 ± 1.76
A320-232	A320	3 196	−2.41 ± 2.19	−1.71 ± 2.05
A320-271N	A20N	661	−3.84 ± 1.96	−4.00 ± 1.85
A321-232	A321	3 167	−2.08 ± 2.01	−1.84 ± 1.83
A330-343	A332, A333, A339	507	−2.52 ± 1.98	−2.12 ± 1.79
A350-941	A359, A35K	970	−3.37 ± 2.43	−3.68 ± 2.36
EMB175	E75L	12 605	−2.21 ± 2.00	−2.12 ± 2.08

SFO Runway 28R AEDT-AE (BADA 4) metric value and difference analysis—Brief summary
The data were analyzed for the final approach to SFO Runway 28R, just as for Runway 28L. Figure 5 and Table 3 summarize the comparisons between AEDT-AE predictions and SLM measurements of LAmax and SEL values.

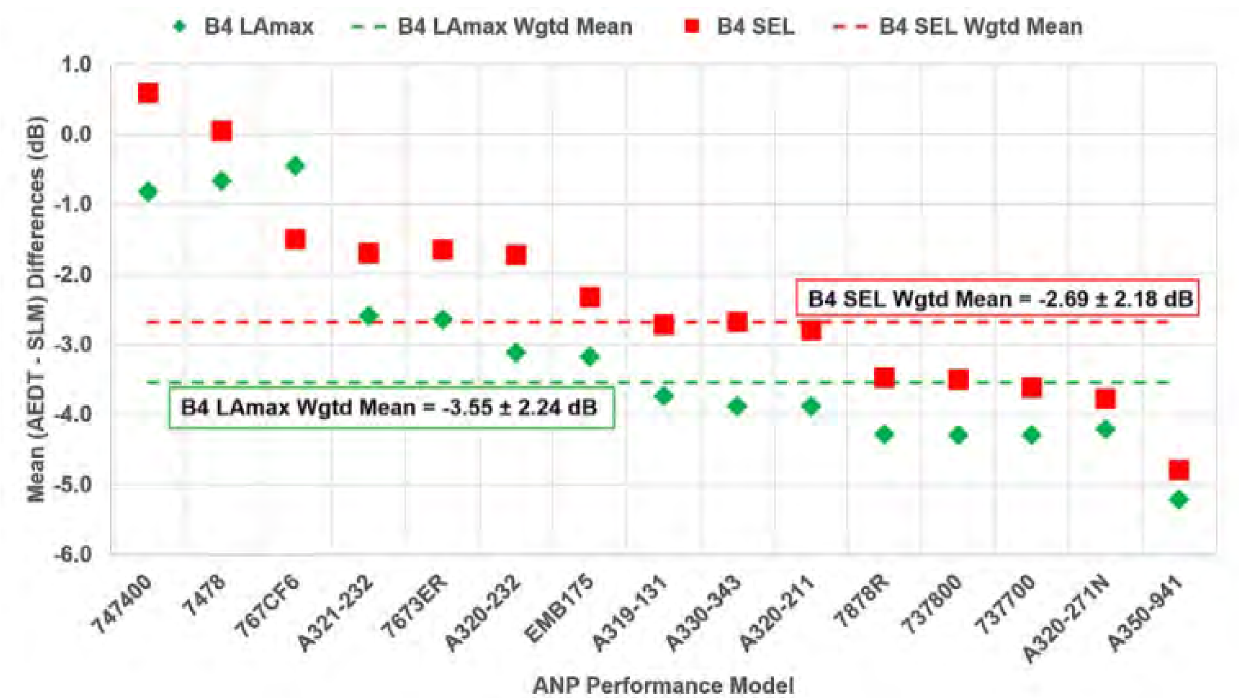

Figure 5. AEDT-AE, SFO NMT-12, Runway 28R. Mean LAmax and SEL differences (AEDT–SLM), by ANP model.

Table 3. AEDT-AE, SFO NMT-12, Runway 28R. Mean and standard deviations of LAmax and SEL differences (AEDT – SLM), by ANP model.

ANP code	BADA code	Subcohort size	AEDT–SLM LAmax difference	AEDT–SLM SEL difference
ALL	All	20 130	−3.55 ± 2.24	−2.69 ± 2.18
737700	B737	870	−4.29 ± 1.68	−3.61 ± 1.62
737800	B738, B739	5 051	−4.29 ± 1.79	−3.50 ± 1.73
747400	B744	269	−0.82 ± 1.96	0.59 ± 1.62
7478	B748	296	−0.66 ± 1.58	0.05 ± 1.52
7673ER	B763	1 500	−2.64 ± 2.33	−1.64 ± 2.13
767CF6	B762	190	−0.45 ± 2.24	−1.50 ± 2.12
7878R	B788, B789, B78X	1 883	−4.28 ± 2.10	−3.47 ± 2.04
A319-131	A319	860	−3.73 ± 2.37	−2.72 ± 2.25
A320-211	A320	1 060	−3.88 ± 1.74	−2.79 ± 1.68
A320-232	A320	1 013	−3.11 ± 2.19	−1.72 ± 2.13
A320-271N	A20N	290	−4.20 ± 2.32	−3.77 ± 2.03
A321-232	A321	2 290	−2.59 ± 1.91	−1.69 ± 1.75
A330-343	A332, A333, A339	247	−3.88 ± 1.76	−2.67 ± 1.70
A350-941	A359, A35K	502	−5.21 ± 2.31	−4.79 ± 2.19
EMB175	E75L	3 528	−3.17 ± 2.17	−2.32 ± 2.10

SIDBY SERFR-DIRECT AEDT-AE (BADA 4) metric value and difference analysis—Brief summary
The data were analyzed for the SERFER-DIRECT approach over the SIDBY waypoint, just as for the final approach to SFO Runway 28L. Figure 6 and Table 4 summarize the comparisons between AEDT-AE predictions and SLM measurements of LAmax and SEL values.

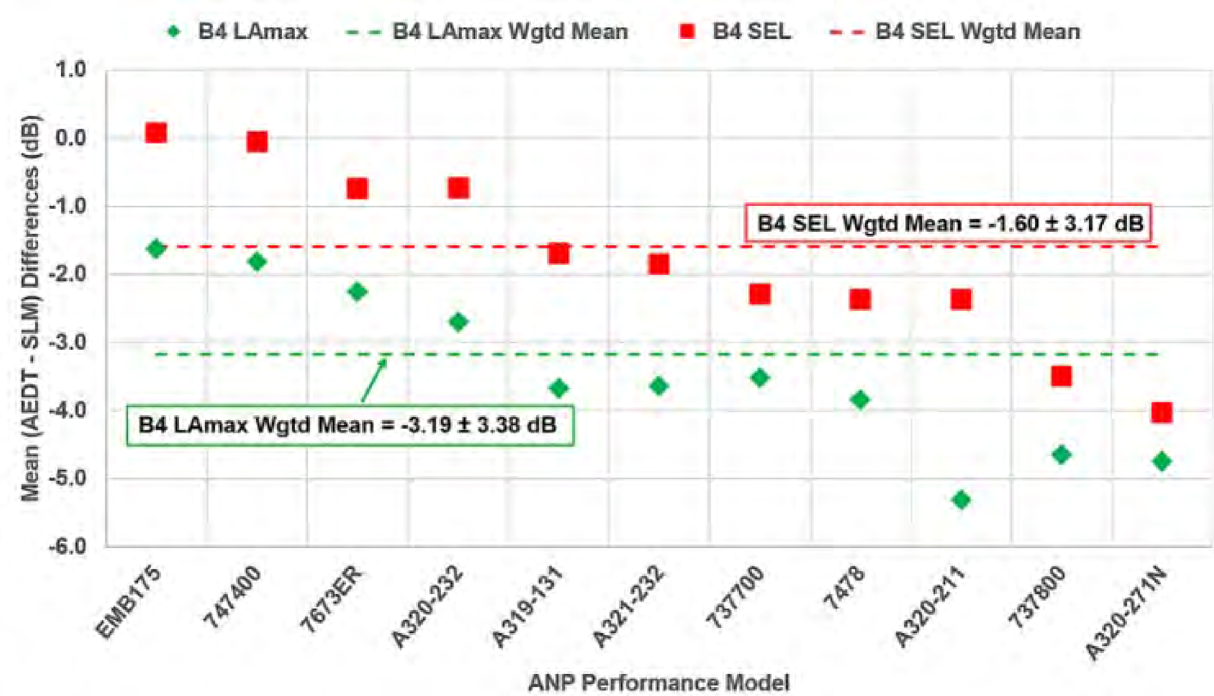

Figure 6. AEDT-AE, SIDBY, SERFER-DIRECT. Mean LAmax and SEL differences (AEDT–SLM), by ANP model.

Table 4. AEDT-AE, SIDBY, SERFER-DIRECT. Mean and standard deviations of LAmax and SEL differences (AEDT–SLM), by ANP model.

ANP code	BADA code	Subcohort size	AEDT–SLM LAmax difference	AEDT–SLM SEL difference
ALL	All	12 181	-3.19 ± 3.38	-1.60 ± 3.17
737700	B737	1 546	-3.52 ± 3.24	-2.29 ± 2.93
737800	B738, B739	2 895	-4.65 ± 2.99	-3.49 ± 2.72
747400	B744	403	-1.81 ± 2.35	-0.05 ± 2.04
7478	B748	366	-3.84 ± 2.32	-2.36 ± 1.99
7673ER	B763	312	-2.25 ± 3.11	-0.74 ± 2.86
A319-131	A319	576	-3.67 ± 3.66	-1.69 ± 3.17
A320-211	A320	546	-5.31 ± 2.61	-2.36 ± 2.36
A320-232	A320	1 323	-2.70 ± 3.28	-0.73 ± 2.90
A320-271N	A20N	243	-4.74 ± 2.58	-4.02 ± 2.47
A321-232	A321	297	-3.64 ± 3.06	-1.84 ± 2.82
EMB175	E75L	3 608	-1.62 ± 3.28	0.08 ± 2.97

Calibrated air speed effects on modeled metric values

An interesting anomaly was noted between AEDT-AE-predicted and SLM-measured LAmax and SEL pairs that can be seen in a pair-wise scatterplot against calibrated air speed (CAS). Figure 7 shows data for two single-aisle aircraft types (ANP performance models 737-700 and 737-800) on final approach to Runway 28L, as observed at SFO NMT-12. AEDT underestimates both LAmax and SEL as noted in the analyses presented above. However, there is another clearly visible effect.

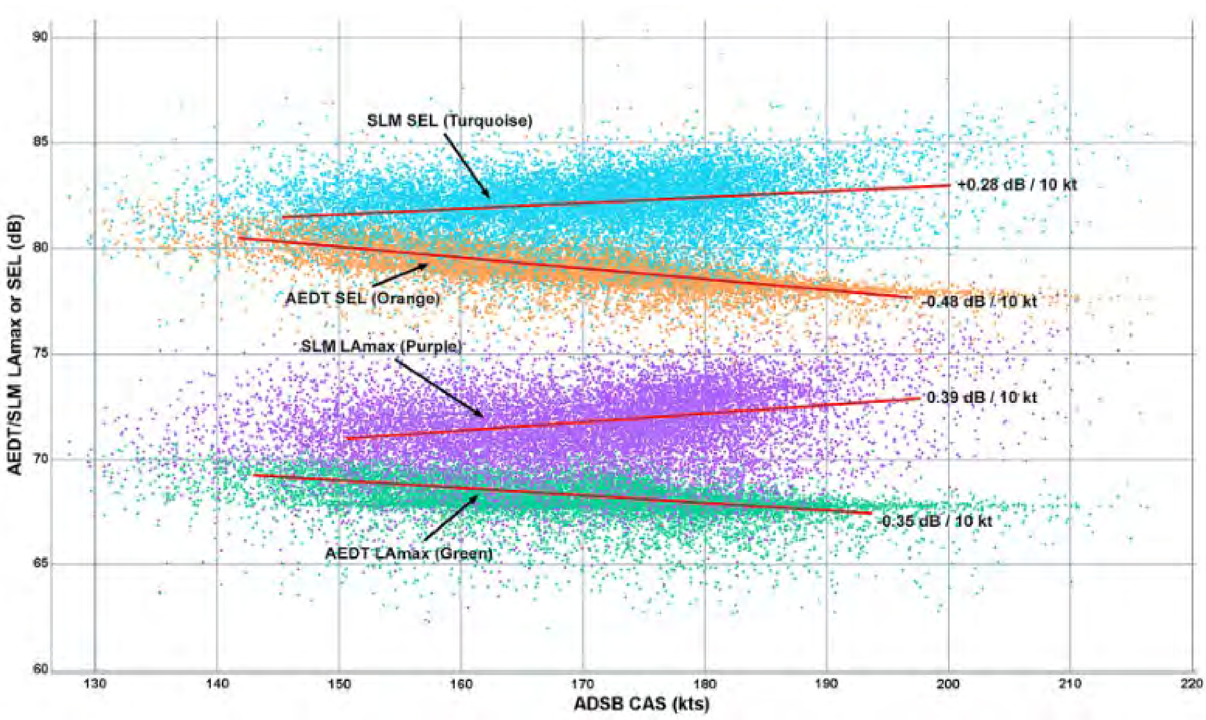

Figure 7. AEDT-AE, SFO NMT-12, Runway 28L. Plots of predicted and measured LAmax and SEL against CAS showing decrease in predicted noise metrics at higher speeds versus increase in measured noise metrics.

With increasing CAS and all other factors remaining constant, physics tells us that sound metrics should increase primarily because of the dependence of airframe noise on airspeed. This effect is indeed observed in the SLM measurements, but AEDT-AE predicts a lessening of noise metrics. The plot shows linear trend lines to illustrate and quantify the rate of metric change, but it is noted that the effect is more complicated than a linear one. This observation is tentatively attributed to the fact that AEDT-AE modeling is based on engine noise estimates, which may in fact decrease as aircraft airspeed changes due to thrust levels, whereas airframe noise sources, especially from auxiliary lift equipment and landing gear deployment, will increase and eventually overpower engine noise, particularly on approach trajectories (Lopes & Burley, 2011). As discussed in the conclusions section, it appears that a more complex and accurate modeling of the physics, particularly of airframe noise, will be needed to make AEDT-AE better conform to ground truth in aircraft arrival situations. Similar results are found for the other route segments (e.g., the final approach to SFO Runway 28R and SERFR-DIRECT over the SIDBY waypoint).

Discussion of AEDT-AE results

For all three route segments, the analyses showed similar AEDT/SLM variation by ANP performance model. AEDT-AE consistently predicts LAmax and SEL values below the levels measured by the SLMs.

Given the complex nature of the AEDT internal calculations, it is difficult to divine exactly the reason for the various underpredictions observed. It is believed that the differences are largely attributable to shortcomings in the SAE-AIR-1845/Doc 9911 model as implemented in AEDT, an underestimation of airframe noise contributions, and a lack of exact knowledge of both the aircraft weight and atmospheric conditions. On the AEDT side, there are many areas of unknown accuracy, such as the validity of noise power distance (NPD) curves derived from certification data and the fact that the modeling is relatively simplistic. For example, without flight operations quality assurance (FOQA) data, the following details are unknown: an aircraft's weight, the thrust employed along the flight profile, when auxiliary lift equipment is deployed, etc. Most often FOQA data are confidential and tightly held by airlines. Weather and atmospheric conditions are similarly hard to control for and would limit the strength of a validation study based on a minimal number of flights.

As with the results from AEDT-R (ANP BADA 3, not described in this summary), the "law of averages" for error cancellation across the fleet mix cannot be relied upon so that AEDT might be able to produce a more accurate average value. In addition, existing AEDT-AE models seem to contradict the expected physics of approach airframe noise generation by not adequately accounting for increased noise levels with increased calibrated airspeed from auxiliary high-lift equipment and landing gear deployment.

Conclusions

In the 2024 JASA paper, as summarized here, a very large dataset of over 200,000 observations was collected and analyzed with pairs of AEDT noise predictions matched with carefully curated SLM noise measurements. The SFO arrivals along three high-density route segments were the focus of our study and the data covered an entire year of observations from July 1, 2021, through June 30, 2022.

Analyses were carried out using the FAA AEDT-R based on ANP/BADA 3 performance modeling with standard profiles and without altitude and speed control data. The resulting statistical data indicate that this type of modeling is overly simplistic and gives far from accurate comparison with ground SLM measurements. For flights passing the SIDBY receptor, it was observed that the estimated altitudes for 9 out of 13 significant aircraft types are significantly below the ADS-B measured altitudes by 2.6 to 4.2 times the standard deviation of the ADS-B altitude distribution. It is noteworthy that, despite these deficiencies, the AEDT-R is the default FAA-approved regulatory mode for AEDT use. Other use of AEDT can go through an approval process on a case-by-case basis.

The analyses also point to a systematic underestimation by AEDT-AE in its predictions for LAmax and SEL metrics by significant but highly varied amounts depending on aircraft type and performance model. AEDT-AE modeling must be improved by adjusting the internal representation of the applicable physics (e.g., the NPD curves and modeling of engine and airframe noise at various stages of flight). In at least some instances, AEDT-AE predicts lower sound metrics (e.g., LAmax and SEL) for aircraft with higher calibrated airspeeds. This contradicts the physics involved and suggests AEDT-AE does not adequately account for airframe noise sources when auxiliary high-lift equipment is in use or landing gear is deployed. It would be ideal to have access to FOQA data, but that is often considered proprietary. It may be possible to estimate factors (i.e., weight, auxiliary lift configuration, etc.) that affect airframe noise generation on average to use more advanced physical models such as the Aircraft Noise Prediction Program (ANOPP2) to better estimate airframe noise (Geissbuhler et al., 2022; Lopes & Burley, 2011; Mahseredjian et al., 2021). Another approach would be to use machine learning methods to characterize the modeling error in terms of ADS-B data, SLM data, and other flight parameters to improve the accuracy of airframe noise component prediction (Alonso et al., 2023).

Major Accomplishments

- Conducted the largest and most statistically significant study of the discrepancies between measured noise data and predicted noise data (using both AEDT-R and AEDT-AE) at two different locations with vastly different DNL levels. In comparisons with previous studies, which at best use tens of flights to draw conclusions, our study is the first ever to look at hundreds of thousands of flights to draw conclusions. The data observations include a full 12-month period, all relevant aircraft types, and all weather conditions. This study is the first of a kind and our team hopes that additional studies can match the low level of error in our statistics.
- Preparation, submission, revision, and acceptance of the 2024 JASA paper with a detailed evaluation of AEDT noise predictions versus SLM-collected data.

Publications

Peer-Reviewed Journal Publications

Rindfleisch, T. C., Alonso, J. J., Jackson, D. C., Munguia, B. C., & Bowman, N. W. (2024). A Large-Scale Validation Study of AEDT Noise Modeling for Aircraft Arrivals. *Journal of the Acoustical Society of America*, *155*(3). https://doi.org/10.1121/10.0025276

Presentations/Proceedings

Jackson, D.C., Rindfleisch, T.C., & Alonso, J.J. (2021). A System for Measurement and Analysis of Aircraft Noise Impacts. *Engineering Proceedings, 13*(6). https://doi.org/10.3390/engproc2021013006. (Presented at the 9th OpenSky Symposium, Brussels, Belgium, November 18-19, 2021).

Alonso, J. J., Shukla, A., Jackson, D. C., & Rindfleisch, T. C. (2023, Jan 23-27), Improving Noise Predictions of the Aviation Environmental Design Tool (AEDT) Using Deep Neural Networks and Sound-level Monitor Data [Video presentation]. *AIAA SCITECH 2023 Forum*. https://arc.aiaa.org/doi/10.2514/6.2023-0735. (Published online on January 19, 2023).

Outreach Efforts

Over the performance period, a number of outreach activities were made to disseminate the result of our work and to inform the public about the complexities of noise predictions resulting from aircraft overflights. We have participated in the 2023 Aviation Noise and Emissions Symposium and presented at both the San Francisco International Airport Roundtable and the San Francisco International Airport Roundtable Technical Working Group. Finally, we held briefings and visualization demonstrations in our visualization room at Stanford University with various cities and municipalities around the San Francisco Bay Area. Professor Alonso was invited to present the results of the 2024 JASA paper in the University of Michigan Aerospace Engineering Department seminar series.

Awards

None.

Student Involvement

Due to the lack of availability of funding, only PhD Candidate Mr. Brian Munguía has contributed to the work during this performance period. Mr. Nick Bowman (now at the Jet Propulsion Laboratory, but formerly a student in the Computer Science department at Stanford University and a contributor to ASCENT Project 053) also contributed some of his time, as a co-author, to the finalization of the manuscript for the 2024 JASA paper.

Plans for Next Period

The focus of the next year of ASCENT Project 053 (expected to begin January 2025) will be on the completion of the full study. This will include arrivals (presented here) and departures (under investigation) to paint a complete picture of the areas where AEDT-R and AEDT-AE provides the required accuracy in the noise predictions, and to more effectively pinpoint areas of potential noise modeling improvements that may be undertaken by AEDT developers. The full study aims to continuously improve the quality of the predictions and, therefore, the quality of proposed new routes accounting for noise impacts on the ground. Our team will also carry out a number of studies to further improve the accuracy of modeling using AEDT, including terrain and ground effects. Finally, improvement, modularization, and documentation of key elements will be continued for our MONA system software for more effective use in our own studies and for shared use with other researchers to conduct similar studies at different institutions and airports. A second journal paper is expected to be prepared by the end of this coming year of execution (2025) detailing the entire set of results but focusing on the departure routes. It is expected that the predictions for departure routes, which are dominated by engine noise, to produce better results than those achieved for arrivals.

References

Alexander, C., Dowell, D., Hu, M., Olson, J., Smirnova, T., Ladwig, T., Weygandt, S., Kenyon, J., James, E., & Lin, H. (2020). Rapid refresh (RAP) and high resolution rapid refresh (HRRR) model development. *100th American Meteorological Society Annual Meeting* (AMS, Boston, MA).

Alonso, J., Alonso, Y., Shukla, A., Jackson, D., & Rindfleisch, T. (2023). Improving noise predictions of the aviation environmental design tool (AEDT) using deep neural networks and sound-level monitor data, *AIAA SCITECH 2023 Forum*, p. 735

FAA (2021a). AEDT Version 3d Technical Manual (Federal Aviation Administration, Washington, DC), Sec. 3.9, p. 145.

FAA (2021b). AEDT Version 3d Technical Manual, Section 3.2 (Federal Aviation Administration, Washington, DC), p. 57.

Geissbuhler, M., Behere, A., Rajaram, D., Kirby, M., & Mavris, D. (2022). Improving airport-level noise modeling by accounting for aircraft configuration-related noise at arrival. *AIAA SCITECH 2022 Forum*, p. 1650.

Lopes, L., & Burley, C. (2011). Design of the next generation aircraft noise prediction program: ANOPP2. *17th AIAA/CEAS Aeroacoustics Conference (32nd AIAA Aeroacoustics Conference)*, p. 2854.

Mahseredjian, A., Thomas, J., & Hansman, J. (2021). Advanced procedure noise model validation using airport noise monitor networks. *50th International Congress and Exposition on Noise Control Engineering,* (Institute of Noise Control Engineering Washington, DC).

Meister, J., Schalcher, S., Wunderli, J.M., & Schäffer, B. (2023). Validation of three inherently different aircraft noise calculation programs, *INTER-NOISE and NOISE-CON Congress and Conference Proceedings,* (Institute of Noise Control Engineering, Washington, DC), Vol. 265, pp. 574–581.

NAS (2018). Enhanced AEDT Modeling of Aircraft Arrival and Departure Profiles, Volume 2: Research Report (The National Academies Press, Washington, DC).