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
Department of Aeronautics & Astronautics
Stanford University
Stanford, CA 94305
650-723-9954
jjalonso@stanford.edu

University Participants

Stanford University

- P.I.: Prof. Juan J. Alonso
- FAA Award Number: 13-C-AJFE-SU-022
- Period of Performance: October 1, 2021 to September 30, 2022
- Tasks:
    1. Completion of an operational prototype of Metroplex Overflight Noise Analysis (MONA) including Aviation Environmental Design Tool (AEDT) integration
    2. Preliminary AEDT noise prediction assessment in day–night average sound level (DNL) 55–65 dB areas
    3. Data-science formats and scientific computing for large-scale airspace analyses
    4. Viable alternative approach routes into the San Francisco Bay Area metroplex

Project Funding Level

With the addition of $90,000 in bridge funding, Year 2 funding was stretched to cover all expenses for both Years 2 and 3 of ASCENT Project 53. Cost sharing above this amount is being provided by various sources. Mr. Thomas Rindfleisch is contributing his time without compensation, and Mr. Donald Jackson is also contributing a substantial amount of time (approximately 65% full-time equivalent) without compensation, to the project. In addition, contractor costs for the development of the MONA project website, the cost of undergraduate student support and summer interns, and some equipment purchases (and installation costs) are also being used to generate cost sharing for this project. During the first 36 months of this project, a total of more than $1.3 M of cost sharing has already been accounted for.

Investigation Team

The investigation team comprises faculty, graduate and undergraduate students, and collaborators, as listed below with their respective areas of expertise and contribution:

1. Juan J. Alonso (P.I., Stanford Aeronautics & Astronautics): overall responsibility for the project and its technical and administrative elements
2. Nick Bowman (graduate student, Stanford Computer Science): MONA project cloud infrastructure, cloud-based execution of AEDT analyses, Apache Kafka-based data collection; October 1, 2021 to September 30, 2022
3. Sanjaye Narayan (graduate student, Stanford Computer Science): flight trajectory database analysis and synthesis, AEDT infrastructure support; October 1, 2021 to September 30, 2022
4. Brian Munguía (graduate student, Stanford Aeronautics & Astronautics): AEDT, cloud-based AEDT study execution, and AEDT debugging; October 1, 2021 to September 30, 2022

5. Donald Jackson (collaborator, independent consultant): overall MONA project infrastructure (servers, databases, and hardware/software monitoring), geographic information system (GIS), web-based visualization deployment, and technical guidance; October 1, 2021 to September 30, 2022
6. Thomas Rindfleisch (collaborator, Emeritus Professor, Stanford University): noise monitoring and filtering, aircraft trajectory collection/processing, and visualization; October 1, 202 to September 30, 2022
7. Aditeya Shukla (undergraduate student, Stanford Aeronautics & Astronautics): artificial intelligence/machine learning classification of aircraft trajectories, real-time sound-level monitoring (SLM) software, artificial intelligence/machine learning noise modeling; October 1, 2021 to September 30, 2022

Project Overview

The MONA project was undertaken to provide objective real-time data, analyses, and reports to key stakeholders and policymakers, to mitigate the noise impacts of the deployment of new NextGen procedures. This system (a) collects and archives air traffic data by using a network of antennae and receivers, (b) analyzes noise impacts by using a variety of metrics, (c) visualizes the resulting large-scale data sets, and (d) uses a network of sound-level monitors to enhance the quality of noise predictions. The focus of this ASCENT project is to improve upon MONA noise predictions through tighter integration with AEDT. In particular, our work is focused on the following three tasks: (a) integration and automation of AEDT's noise analysis capabilities, (b) validation and verification (V&V) of AEDT's noise predictions in DNL 55–65 dB areas, and (c) proposal of 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 described above, including (a) an ability to automate complex noise analyses in metroplexes so that they are available nearly in real time after the preceding 24-hr period, (b) a better understanding of the accuracy of AEDT's current noise models in low-noise (DNL 55–65 dB) areas and the reasons for the discrepancies (if any) in existing predictions, and (c) recommendations to software developers regarding flexible architectures and APIs for AEDT, to make the tool more versatile and generally applicable. AEDT predictions are built around the policy context of an average annual day. Most of the V&V results produced and shared by the MONA team had focused on a cumulative daily basis, for which flight track data were directly collected. In a major accomplishment in this period of performance, we automated the analysis of every flight into San Francisco International Airport (SFO) for an entire year (July 1, 2021 to June 30, 2022); therefore, some of our preliminary results also include DNL for an actual entire year of flight operations. The focus of the work reported here is on arrivals at SFO, primarily those at runway 28L.

Background and Previous Accomplishments

The MONA project started approximately 4 years ago, with the main objective of providing objective real-time data, analyses, and reports to key stakeholders and policymakers to aid in mitigating the noise impacts of the deployment of new NextGen procedures. Since then, we have developed and deployed a system that (a) collects, archives, and makes available air traffic data by using a series of networked antennae and receivers 24/7, (b) analyzes noise impacts by using a variety of metrics (based on both a MONA-developed noise prediction tool and the noise prediction tools within AEDT), (c) visualizes the resulting large-scale data sets in a simple, user-friendly manner by using a bespoke website as well as Uber's kepler.gl (n.d.) and deck.gl (n.d.) large-scale data visualization toolboxes, and (d) has deployed a small network of low-cost, Stanford-owned, sound-level monitors scattered across the South Bay in the Bay Area, including data from the noise monitors deployed by SFO to cross-calibrate measurements by MONA and SFO monitors, collect noise measurements from a wider geographic range, and enhance noise predictions so that they exactly describe the actual noise levels experienced.

The longer-term objectives of the MONA project are to (a) ensure the V&V of all noise predictions provided (by AEDT or other tools) in both areas near the airport and other areas farther 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 interpretation 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.

At the present time (December 2022), the MONA software continues to develop and mature, to enable completion of the main research tasks in ASCENT 53. MONA has deployed a small network of Automatic Dependent Surveillance–Broadcast (ADS-B)/multilateration (MLAT) antennae, and we have developed the software necessary to merge the data streams from all these antennae, including deduplication 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, substantial scrutiny has been paid to understanding the best ways to use AEDT (by understanding how to most accurately model aircraft trajectories, aircraft equipment, and aircraft noise), so that any comparisons with experimental data present the results obtained from AEDT in the best possible light.

Second, MONA has achieved a level of integration with FAA's AEDT software that enables fully automatic processing of noise exposure at arbitrary receptor locations for arrival routes into the San Francisco Bay Area airports. As a preview of the results presented in this yearly report, the level of cloud-based automation achieved by the ASCENT 53 team now allows us to process an entire year of flights (including hundreds of thousands of operations) in approximately 2.5 calendar days, thus enabling the collection and processing of unprecedented amounts of data that allow statistically significant conclusions to be drawn. Third, MONA has now fully incorporated measurements from networked sound-level monitors via the Apache Kafka system, and has developed and validated approaches for non-aircraft-noise filtering (of the raw noise data), according to digital filtering, aircraft position information, and automated identification of background noise levels that have been validated and verified. These techniques have also been markedly improved during the period of performance, with extensive help from our FAA project manager, Mr. Susumu Shirayama, who has worked side by side with our team.

Finally, although not an explicit task of ASCENT 53, we have continued our efforts to interface the above-described MONA software modules with the kepler.gl open-source visualization framework, to enable visualization and animation of aircraft positions and paths, noise predictions, various routes and procedures, etc., to better communicate the results of our work (Figure 1).

Figure 1. MONA visualization using kepler.gl (n.d.) and deck.gl (n.d.) of traffic patterns in the San Francisco Bay Area, including a 24-hr view of aircraft traffic patterns. Trajectories are colored by altitude, with purple/magenta indicating low altitudes and blue indicating high altitudes.

For the current period of performance, our main objectives can be described (from the approved proposal document) as follows:

a) Completing an operational prototype of MONA that (a) integrates ADS-B paths and possibly other FAA sources of information (such as AEDT-Optimized Threaded Track), (b) AEDT analyses, (c) noise measurements, and (d) visualization capabilities
b) Completing our assessment of the noise prediction capabilities (from experimental data) of AEDT in DNL 55–65 dB areas
c) Extending, perfecting, and evaluating the MONA prototype to a wider range of test sites and traffic types
d) Producing an analytic account of the level of accuracy to which we can measure sound levels embedded in typical background noise with a network of sound monitors
e) Correlating observed noise with specific causes relating to the aircraft state

f) Investigating the best-suited formats (including data-science-friendly formats such as Parquet for Hadoop and others) for storing flight track information (and associated metadata) and processing all information through standard data-science workflows
g) Proposing alternate approach/departure routes in and out of the San Francisco Bay Area metroplex that can reduce noise impacts while maintaining throughput, efficiency, and safety

The remainder of this report describes the progress that we have made in each of these seven elements of our research program. The report mirrors the results presented at the ASCENT Program Annual Meeting held in Alexandria, Virginia, on October 25–27, 2022.

Task 1 - Completion of an operational prototype of Metroplex Overflight Noise Analysis (MONA) including Aviation Environmental Design Tool (AEDT)

Stanford University

Objectives

In previous annual reports, we have described the incremental improvements in the various components of the MONA system, including collection and ingestion into a modern database of ADS-B and noise data; preparation of trajectory data for consumption by AEDT; automation of large numbers of analyses using AEDT; and extraction and archiving of AEDT output study data to compare predicted and experimental findings. The main accomplishment in this domain during the past year has been the increase in the functionality and maturity of our entire MONA system, thus allowing us to compare simulated and experimental noise data for an entire year of arrival flights into SFO. Such a comparison has not been achieved in any noise study in the literature to date, to our knowledge. We are now routinely able to run a simulation of an entire year of arrivals into SFO (along runways 28R/L) in approximately 2 days. Consequently, we can observe differences in the predictions from AEDT (and comparisons with experimental data) while varying many simulation parameters affecting AEDT predictions (e.g., trajectory simulation approaches, Base of Aircraft Data [BADA] 3 vs. BADA4 modeling, weather simulation data, equipment databases and matching, etc.) The MONA system is a research tool that allows us to rapidly perform studies enabling better assessment of the predictive quality of AEDT runs.

In the remainder of this section, we provide short descriptions of all elements of the currently operational MONA prototype. This description is a shortened version of the description provided in last year's report, which is provided here to contextualize the results presented in subsequent sections. Our automation method is based on our own cloud-based AEDT execution environment, which we have named remote AEDT (**`raedt`**), which works on Google Cloud Project instances of arbitrary size (number of processors, memory, etc.).

As a consequence of community complaints, resulting from the changes in air-traffic patterns over the San Francisco Bay Area metroplex during the past 5 years, it became increasingly clear that there is a dearth of high-quality aircraft noise data (from measurements and/or predictions), particularly in areas away from the airport boundary that have not traditionally been the main focus of noise complaints. In addition, through several community interactions, we became aware of the difficulties involved in relating potential flight route changes to noise impacts on the ground. This lack of actionable data and methods to effectively communicate with broad, and-often-non-technical, communities led us to develop the MONA system. The MONA project set out to achieve the following objectives:

- Measure and analyze ground noise data generated by aircraft overflights in complex metroplex situations
- Create, curate, and archive experimental data sets that can serve as an openly available database for V&V of improved noise prediction methods
- Fully automate noise analyses based on the AEDT without a need for user intervention
- Share key analysis results with broad communities of stakeholders through compelling interactive visualizations

The MONA system has evolved into a complex open-source project with multiple elements, which are described below.

Research Approach

Measurement and Collection of Data

To quantify and analyze the noise impact of aircraft overflights, both the trajectories of aircraft flights and the resulting ground noise must be known. To that end, MONA collects the following types of data:

- Aircraft flight profiles (via ADS-B) and speed over ground
- Sound levels
- Flight and aircraft metadata
- Air traffic routes and procedures
- Wind and weather conditions

Sensor Controller

The measurement of sound levels and reception of ADS-B transmissions require a distributed network of sensors mounted outdoors throughout the geographic region of interest, and a means to access/retrieve the data. For the MONA project, we have implemented a series of sensor controllers, incorporating a single-board computer, a global positioning system (GPS) receiver (to provide a highly accurate time pulse, as well as three-dimensional location), with both network connectivity and power via Power over Ethernet (PoE). These components are integrated within a waterproof/weatherproof enclosure, to support long-term outdoor deployment. The sensor controller runs a Network Time Protocol (NTP) daemon, configured to use the output of the integrated GPS receiver (in pulses per second), to provide a Stratum-1 time base, thereby minimizing time differences among our distributed network of sensors. We developed software to collect each sensor's output and transmit/publish the data in real time via the Internet to a centralized aggregator hosted at a data center. A single sensor controller can simultaneously support both ADS-B reception and SLM. Because of the long-term field deployment of the sensors, autonomous operation and secure remote access are essential.

Figure 2 shows our standard MONA ground station installation and a view of the sensor controller components inside their weatherproof enclosure.

Figure 2. Sensor controller rooftop deployment with ADS-B and SLM (left); sensor controller components (right).

ADS-B Receiver

The primary ADS-B receivers in the MONA network are based on the PiAware/`dump1090-fa` software by FlightAware (AeroAPI, n.d.), by using a standard RTL-SDR dongle (inside the sensor controller enclosure in Figure 2, right), connected to an ADS-B antenna affixed to the same enclosure. Every second, the JSON output of `dump1090-fa` is captured by a software daemon, and the ADS-B messages within are minimally processed and then transmitted/published to our centralized aggregator, implemented as an Apache Kafka cluster. The collector daemon also publishes receiver metadata (including GPS location and sensor controller status) to the same aggregator.

Sound-Level Monitoring (SLM)

We use Convergence Instruments (CI) SLMs, connected via Universal Serial Bus to the sensor controller, to measure noise. Another software daemon captures the outputs of the SLM and transmits/publishes them in real time to a centralized server, again by using Apache Kafka. Recent models of the CI SLM optionally support a USB-Audio feature, providing access to the sampled audio waveform, which we selectively save/transmit to capture both noise metrics and audio recordings of aircraft overflights. The SLM collector daemon publishes SLM metadata (including SLM configuration, GPS location, and sensor controller status) to the central server.

Flight and Aircraft Metadata

Aircraft ADS-B positions alone do not provide a complete description of the flight. Important/valuable missing metadata include:

- Arrival and departure airports
- Assigned runways
- Air traffic control assigned routes and procedures
- Airframe, engine, and ownership

Arrival and departure airport information can often be obtained via external API access or inferred by comparison of the first or last known ADS-B position with airport/runway locations. Air traffic control (ATC) assigned procedures, routes, and runways can be inferred by comparison of an aircraft's trajectory to the locations (and sequences) of waypoints and runways. An area of ongoing development is the integration/incorporation of the FAA System Wide Information Management (SWIM) data feeds, to combine this rich source of metadata with ADS-B aircraft positions. SWIM messages are ingested into Kafka topics, thus providing reliable reception of these real-time data feeds. Airframe, engine, and ownership information are obtained by joining the aircraft's ICAO24 unique identifier (included in the ADS-B message) with aircraft registration datasets, including the FAA Aircraft Registry (for US aircraft), and OpenSky's Aircraft Metadata Database (for other aircraft).

Air Traffic Routes and Procedures

FAA Coded Instrument Flight Procedures (CIFP) is a definitive source of information that we download, parse, and archive monthly. The CIFP provides data on airport, runway, and waypoint locations, which we use for geospatial processing and queries. Flight procedures are converted to a directed-graph representation, and then processed with both standard and custom graph algorithms.

Wind and Weather

ADS-B messages usually provide the aircraft's ground speed but do not provide its airspeed, which is an important factor for the prediction of the resulting noise. We obtain wind speed and direction measurements from the National Oceanic and Atmospheric Administration (NOAA) High-Resolution Rapid Refresh (HRRR) dataset, and in conjunction with the ADS-B provided ground speed and heading information, we estimate the net airspeed, which is used to define the specific aircraft trajectory for noise prediction.

Data Collection, Archival Storage, Access, and Management

Real-time ADS-B messages, SLM measurements, and SWIM data feeds are received and stored by a distributed-event streaming platform implemented by using Apache Kafka (n.d.). These streams are processed and subsequently ingested into a Postgres database, augmented with both PostGIS (supporting geospatial queries) and TimescaleDB (supporting very large time-series tables). ADS-B messages from multiple receivers are deduplicated and segmented into flights, and relevant metadata are added. Trajectories are included in each flight record/row, encoded as PostGIS 4D LineStrings, thus enabling arbitrary spatiotemporal queries supporting statistical analyses on vast numbers of flights over arbitrary time periods. Our work frequently requires knowledge of the point, distance, and/or time of closest approach (PCA, DCA, or TCA) of an aircraft trajectory to a location of interest (LOI) such as the position of an SLM. PostGIS queries can dynamically compute, filter, and return these values for any stored flight trajectory and LOI combination.

Data Processing and Analysis

The raw data acquired by the MONA system must be processed before they can be input in our analyses and used to compute statistics for the information collected. This section describes some of the data analyses that we have automated in MONA. After aircraft trajectories and measured noise have been captured, stored, and made available for future use, we process, analyze, quantify, compare, categorize, and summarize the noise impacts.

Attribution of Sound Levels to Aircraft Overflights

The sound-level measurements obtained both from MONA SLMs and other providers (such as SFO’s noise monitoring terminal [NMT] stations) include sampled aggregate sound pressure levels generated from every source, but only the noise resulting from aircraft overflights is relevant to our research. Several techniques for attributing sound peaks to aircraft are described in the literature. Particularly relevant examples include threshold and duration, directional and/or arrayed microphones, and spectral identification/categorization. In our experience, an effective method is Determined Aircraft Position/Location for Aircraft Noise Extraction (DA-PLANE), This algorithm involves computing the time and distance of an aircraft's closest approach to the SLM location (from ADS-B trajectory data), which gives the estimated time of the aircraft’s sound peak at the SLM. Subsequently, we use time-series filtering and analysis to locate peaks above the time-varying background in the sound profile that may have been caused by aircraft overflights. These peaks are then time-matched with the closest approach data to isolate and identify the sound peaks resulting from specific aircraft. The net profile amplitudes of isolated peaks above the background are then analyzed to extract the desired noise metrics for each identified overflight event. Other implementations of this technique include those of Harding and Ferrier (2014), and Giladi (2020). In the MONA system, the maximum LAeq$_{1s}$ value and SEL metrics are extracted and stored in the database, with relations to both the flight (aircraft) and SLM (measurement) location.

Metric Computation

With aircraft trajectories encoded as geospatial datatypes and measured noise metrics attributed to specific aircraft flights and precise locations, we compute standard noise metrics such as number-above, DNL/Community Noise Exposure Limit (CNEL), time-above, and background level. Non-noise metrics, such as overflight counts per day (within a distance/range), are also computed.

Aircraft Noise Prediction

Deploying SLMs with sufficient numbers and geographic density to obtain measured noise data is not feasible throughout an entire set of geographically connected airports (cost and logistics are two major constraints). However, all air traffic can be captured via ADS-B by deploying a relatively small number of receivers over the metroplex area. Ideally, we could use the collected trajectory data to predict the noise generated by each and every aircraft on a fine-grained receptor grid to estimate noise metrics across the entire region of interest.

The FAA's AEDT is the required software application for assessment of U.S. regulatory actions related to aircraft noise and emissions. Our (aspirational) goal is to run AEDT predictions for every aircraft flight across the San Francisco Bay Area each day, then aggregate the resulting predicted noise metrics, to provide quantified noise impacts across the entire metroplex, as a function of location and time.

To this end, we have completed a software environment to:

- Automate AEDT study creation, execution, and metric result extraction
- Accurately model AEDT flight trajectories by using ADS-B data
- Evaluate and compare AEDT's noise predictions to measured noise levels, in a manner similar to that of Giladi and Menachi

More detailed descriptions of these individual tasks follow.

AEDT Automation

Current AEDT implementation and workflows are focused primarily on desktop computer applications, via its graphical user interface. This usage model does not support the automated processing of thousands of flights per day over many years. To implement an automation facility, we leveraged AEDT's use of, and reliance on, a Microsoft SQL Server database. Using AEDT's database schema documentation in conjunction with a database table "diff" tool that we developed, we gained an understanding of how to create and populate the tables necessary to describe a complete AEDT study. We then developed a software library to facilitate scripted study creation over a network connection to the SQL Server database used by AEDT.

AEDT provides a command-line utility, `RunStudy.exe`, to initiate the execution of a specified study that we can invoke over the network. An AEDT study's computed metrics are written into the SQL Server database, so that we can also access and extract these results over the network.

We created a virtual machine (VM) disk image including AEDT and all supporting packages preinstalled, which can be instantiated and run at any scale on a commercial cloud provider. We then developed a study-executor application that takes a study description as input; orchestrates and connects to an AEDT VM; creates an AEDT study by using the trajectory of the flight's database ID (provided in the study description), including altitude and speed controls to match the observed trajectory; executes the study; and extracts/stores the metric results in our database. Next, we developed a study-creation application that generates any number of study descriptions (based on SQL queries specifying any desired database column criteria) and submits each resulting study description to a job queue. Finally, we enhanced the study executor to query the job queue for a study description to process.

As a result, we can run any number of AEDT studies in parallel and are limited only by the number of AEDT VMs and study executors that we create. Both the job and extracted-metrics queues are implemented by using the Apache Kafka (n.d.) cluster.

AEDT Trajectory Modeling from ADS-B Data

AEDT is typically used to model flights from a number of specified ground track positions (without altitude). AEDT combines the specified ground track with flight performance models from the Aircraft Noise and Performance (ANP) Database and EUROCONTROL's BADA to simulate the aircraft's trajectory for its predictions. This computed, simulated trajectory may differ from the trajectory reported by ADS-B. AEDT provides additional functionality to add altitude and airspeed control codes to the ground track (Section 3.9.1, "Track Control Flights," in the AEDT3d Technical Manual), which we use to more closely model the reported trajectory.

The ADS-B trajectory processing steps that we use include the following:

- Smoothing and filtering to remove anomalies that AEDT would reject (e.g., increases in altitude during a descent).
- Line Segment Simplification (Douglas & Peucker, 1973; Ramer, 1972).
- Estimation of the aircraft's airspeed, using ADS-B provided ground speed and heading, in combination with wind speed and direction data obtained from NOAA.

Comparison of AEDT noise predictions with measured noise

Our AEDT studies specify the LAmaxand SEL noise metrics, per flight, at each receptor (SLM) location. These metric values are stored in our database, with relations to the flight and location, as we do with the measured noise peaks attributed to aircraft (described previously). With both predicted and measured noise, comparisons are made across various cohorts of flights, which can be specified by filtering, grouping, analyzing, and reporting by any available set of metadata fields (e.g., aircraft model and route). During the past year, we have spent most of our time performing AEDT-based simulations and predictions and comparing them with the experimental data that we have collected. The results obtained from these comparisons are the main content of this annual report. The ability to display the results of these comparisons is key to the understanding of both the differences between predictions and experiments, and the potential root causes of these differences.

Task 2 - Preliminary AEDT Noise Prediction Assessment in DNL 55–65 dB Areas

Stanford University

Objectives

Disclaimers

The results in this section represent our V&V efforts for AEDT conducted during the current period of performance (October 1, 2021 to September 30, 2022). These results represent our first attempt at yearly comparisons between AEDT predictions and experimental noise data. As such, and until improved results are published in a peer-reviewed journal (as of February 2023, we have completed substantially more comparisons than the work presented in this annual report) the results here should be considered preliminary. The findings provide an indication of our main observations but lack the level of confidence required to make sufficiently strong statements. Moreover, whereas AEDT is the tool used for regulatory purposes in the United States, we have used a version of AEDT that we call AEDT-AE, which uses the collected aircraft track data, and both BADA4 performance models and altitude and speed controls, to complete the simulations. We do not claim that AEDT-AE has any regulatory value.

The noise prediction modules in AEDT, on the basis of noise–power–distance (NPD) relationships and certification data, were developed and calibrated mainly for areas close to airports with objectionable noise (> DNL 65 dB), at a constant velocity (160 knots), and for a particular aircraft high-lift system and landing gear configuration. Even including efforts such as those in ASCENT Project 43 (which reevaluated the NPD curves by using Aircraft Noise Prediction Program [ANOPP] analyses and the ability to change the aircraft configuration during arrival/departure procedures), there is evidence that the accuracy of AEDT's predictions in areas of relatively lower noise (between DNL 55 and 65 dB) may warrant review and improvement. For these reasons, in this series of tasks, we have undertaken a preliminary evaluation of the accuracy of AEDT's predictions when measured against sound level readings from two different locations in the arrival paths to SFO: one relatively close to the airport and one further away.

Our main accomplishments over the past 12 months include:

- Completion of the MONA system to archive, process, and query all measured and predicted data (described in a previous section)
- Completion of the AEDT-AE processing system: creation of single flight studies, study execution, and extraction of study results, at any desired scale
- Completion of preliminary and statistically significant comparisons of measured versus AEDT-AE-predicted noise, at two locations, for every flight, over 12 months

In our previous annual report, we described our results (circa October 2021), which were based primarily on an early prototype of MONA and all its constituent modules and, at most, 1 month (mid-July to mid-August 2021) of arrivals data over two different SLM locations. During the past 12 months, we have continued to improve the modeling capabilities and the noise processing algorithms in AEDT-AE and MONA, and we have been able to process substantially more flights (an entire year's worth) containing many more observations of all types of aircraft, under a wide variety of atmospheric and weather conditions. We consider the data set used in the preliminary results presented here to be both statistically significant and representative of the variability that would be observed over a representative period of time (1 year).

Data Set

Two common threads have emerged from recent assessments of various noise predictions in the literature. First, in all such studies, only a handful of flights have been examined, and therefore the variations in all potential input variables affecting the predictions (aircraft weight, weather patterns, high-lift system deployment, etc.) are not observed thoroughly and frequently enough to perform any significant statistical analysis. Such dearth of data also prevents detailed studies to attribute the discrepancies between measured and predicted noise levels to their actual sources, thus preventing the improvement of existing models. Secondly, the low volume of data does not allow the slicing of the datasets by aircraft class, atmospheric conditions, or even geometric position relative to the SLM locations: if the datasets are small to start with, further slicing only decreases the size of the resulting dataset leading to unconverged statistics that cannot be relied upon. The outcome of these shortcomings is that any attempt at improving current noise modeling strategies is impossible without dataset of sufficient size to provide statistical significance. For these reasons, we have focused on creating a dataset with approximately 135,000 flights (and 135,000 x 40 noise observations at PCAs; significantly more data points are available if the entire time history of the noise recordings is considered) that is described in more detail below.

Our data set for both AEDT-AE predictions and SLM measurements contains all arrivals into SFO runways 28L/R for a period of an entire year: July 1, 2021 to June 30, 2022. In this report, we focus on noise predictions and measurements at two main SLM locations: SFO-NMT-12 and SIDBY:

- SFO-NMT-12 is an SLM owned by SFO and operated for SFO by EnviroSuite; it is located close to the flight tracks for final approach into runways 28L/R, approximately 6 mi from touchdown. The measured DNL at this location is ~60 dB. This location is not quite within the DNL 65 dB area but is very close. Flights on final approach to SFO that fly by this location are normally at an altitude of approximately 1,700 ft and an airspeed of approximately 160–180 knots.

- SIDBY is a Stanford-owned SLM whose measurement accuracy has been assessed with a colocated SFO sound monitor and is located at the SIDBY waypoint. The SIDBY waypoint is overflown by aircraft following the SERFR, PIRAT, and BDEGA approach routes to SFO. SIDBY is located approximately 12 mi from touchdown at SFO runways 28L/R. Although we collect data for all aircraft overflying the SIDBY waypoint, our analysis reported here focuses on (a) all flights overflying SIDBY and (b) flights overflying SIDBY that approach SFO via the SERFR route only. We classify the data in this way to assess the impacts of various approach routes into SFO. The measured DNL at this location is ~46 dB.

A map of the area southeast of SFO is shown in Figure 3, and the locations of the two SLMs and typical approach paths into SFO are colored by flight altitude (green/blue denote high altitudes, whereas red/magenta denote altitudes close to the ground.)

Figure 3. Locations of the two SLMs (SFO-NMT-12 and SIDBY) used in this study.

The total data set contains approximately 135,000 distinct flights. Predictions / simulations use AEDT-AE and a separate study for each of these flights. As each flight is simulated, we compute and extract noise metrics at both SFO-NMT-12 and SIDBY but also (although not reported here) at approximately 35 other SLM locations for future assessments and comparisons. All aircraft types are observed in our database, although the main aircraft types are regional jets and single-aisle aircraft. We purposefully exclude general aviation (GA) aircraft from our data set, to focus on noise comparisons for the commercial fleet. In our first complete version of AEDT-AE, the nearly 135,000 studies completed with our `raedt` software required five entire days to compute by using 128 VMs on Google Cloud. At the time of writing of this report, the computational time required to perform a similar study is less than 2 days, as a result of various processing improvements.

For the SFO-NMT-12 location, the relevant statistics are as follows:

- A total of 134,178 flights were initially considered.
- Flights occurred over an entire contiguous 12-month period, under all types of weather conditions, such as rain, various humidity and temperature levels, winds, etc., thus representing the typical variations observed at SFO.
- A total of 4,057 GA flights were discarded.

- An additional 34,870 flights were discarded because the associated noise events did not meet our criteria for goodness of fit (i.e., the recorded noise events were deemed to include additional noise sources beyond aircraft noise or had been distorted by atmospheric turbulence, to the point that our confidence was lower than required).
- A total of 5,568 additional flights were left out of our data set because more than one flight was observed in the neighborhood of the PCA at the TCA.
- Finally, 3,417 overflights were discarded because they did not meet additional criteria to be counted, including altitude, distance, and heading constraints that we had imposed on all overflights.
- The remaining flights for this location, for the 12-month period starting on July 1, 2021, numbered 86,266.

For the SIDBY location, the following are the relevant statistics:

- 64,885 flights were initially considered
- 1,579 GA flights were discarded
- An additional 41,775 flights were discarded because the associated noise events did not meet our criteria for Goodness of Fit (i.e. ,the recorded noise events were deemed to include additional noise sources beyond aircraft noise or had been distorted by atmospheric conditions to the point that our confidence was lower than).
- A total of 280 additional flights were left out of our data set because more than one flight was observed in the neighborhood of the PCA at the TCA.
- Finally, 7,960 overflights were discarded because they did not meet additional criteria to be counted, including altitude, distance, and heading constraints that we had imposed on all overflights.
- The remaining flights for this location, for the 12-month period starting on July 1, 2021, numbered 21,056

Although we may run larger data sets in the future, we believe that these data sets are sufficiently large to support the preliminary conclusions presented in this report. As described earlier in this annual report, we believe that this data set is the largest of its kind; typical publications in the literature have used data sets of 10–50 individual flights.

Among the various SLMs from which we have data, these two are particularly interesting because, although they are both under arrival tracks, they are located in two areas with highly different noise levels. SFO-NMT-12 is presumably in an area for which the noise predictions of AEDT-AE are relatively accurate (near the airport), whereas SIDBY is substantially farther from the airport and is in an area that was not specifically targeted during the development of the noise prediction algorithms in AEDT-AE.

Research Approach

To accomplish the objectives of this task, we pursued a number of steps that are not described in detail here, including the following:

1. Data acquisition and archiving for noise measurements at the two locations, SFO-NMT-12 and SIDBY. We have completed the acquisition of the raw noise data (Leq samples at 1-s intervals), over a period of approximately 3 years. All these data have been curated so that they provide meaningful comparisons with AEDT predictions.
2. As a pre-processing step to the V&V portion of this work, we completed the development of a series of non-aircraft noise removal algorithms that combine filtering techniques, automatic identification of multiple aircraft peaks, automatic detection of background and peak noise levels, and real-time information regarding the position, velocity, and heading of the aircraft to maintain high levels of accuracy. We also included a goodness-of-fit measure based on a least-squares fit to a theoretical noise model. As described above, we have a very high degree of certainty that the overflights retained truly correspond to actual aircraft, without additional non-aircraft sources of noise present.

Note that the raw SLM data at multiple locations, including SFO-NMT-12 and SIDBY, are currently captured and stored in a Apache Kafka centralized DB with associated timestamps which can be retrieved by running respective SQL queries. These data come from calibrated networked Convergence Instruments (n.d.) equipment that we have installed at various locations around the San Francisco Bay Area (as described earlier in this report), which have been tested with colocated sound measurement equipment loaned by SFO and have been found to agree with that equipment to within 0.1–0.2 dB. Specifically, for SFO-NMT-12, as described above, the noise data have been provided by EnviroSuite on behalf of SFO.

The following figures are meant to provide statistically significant information but only preliminary conclusions, because we have yet to understand the reasons for the discrepancies observed. These reasons must be understood before final conclusions are drawn from this study. The data set includes all types of aircraft, but predominantly E75L, B73X (B737-800, B737-900), and A320/A321. We have removed all general aviation flights from this data set, and we have ensured that no flights are included whose line-of-sight elevation at the PCA to a SLM is less than 40° (so that any aircraft not in proximity to the SLM are disregarded).

Preliminary Results for the SFO-NMT-12 Location

Preliminary observations resulting from processing of the data predicted and collected at the SFO-NMT-12 are presented below. Figures 4 and 5 show coarse-grained histograms (in the sense that they contain all aircraft of all types over a 12-month period) for both LAmax and SEL for all 86,266 flights considered in this study. The data have been binned in 0.5-dB intervals and represent the actual noise metric values (for each individual flight) for both AEDT-AE predictions (in orange) and SLM measurements (in light blue), after removal of background noise. The data set includes only aircraft/flights that can be modeled with BADA4. Several observations can be made from these two figures. First, the variability and multimodality of the AEDT-AE-predicted data are quite substantial and are absent in the SLM measurements, which appear to show a Gaussian-like distribution for the aircraft observed. The AEDT-AE prediction distribution is multimodal, thus indicating the provenance of each bar in the histogram from different aircraft types and classes. At this SLM location, when aircraft are on final approach to SFO runways 28L/R, little variability is attributable to differences in altitude and airspeed, or to the state of the high-lift system and undercarriage. The AEDT-AE predictions consider seasonal variations in weather that smooth out some of the peaks of the multimodal distribution. In contrast, the SLM data are heavily homogenized and show no indication of various types of aircraft.Our conjecture is that atmospheric, turbulence, and weather conditions might result in a type of mixing that leads to smoother distributions. We have been conducting finer slicing of the data set, by aircraft type, to better understand these effects. Our results will be discussed at the next ASCENT meeting. The difference in the means of the AEDT-AE and SLM distributions in LAmax is approximately 3 dB (underprediction by AEDT-AE).

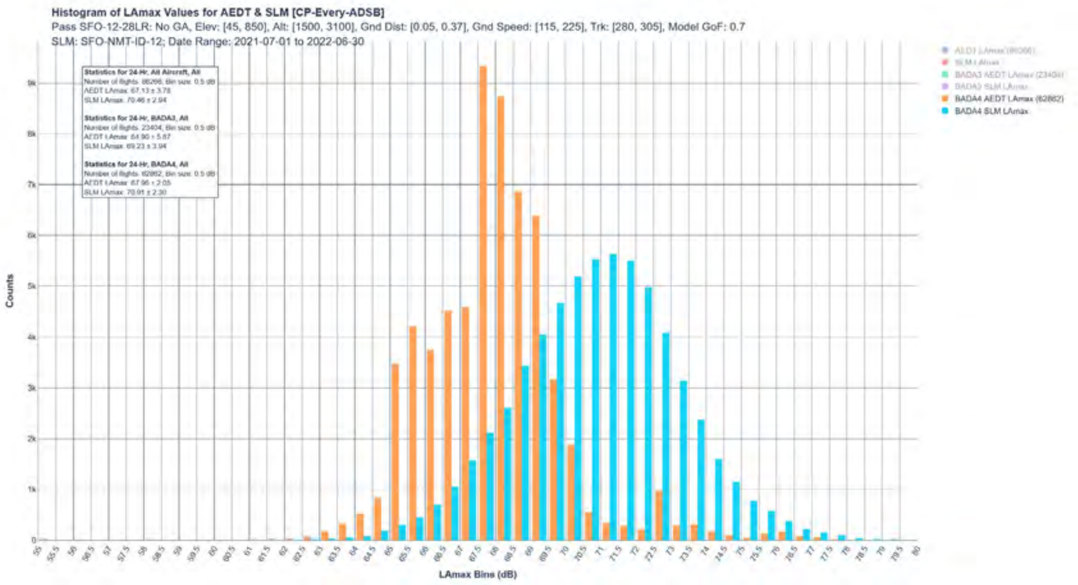

Figure 4. Histogram with the LAmax values from AEDT-AE predictions (orange) and SLM measurements (light blue) at the SFO-NMT-12 location. LAmax data are binned into 0.5-dB intervals. **Preliminary data: please do not cite or quote.**

Figure 5 shows similar results for the exact same data set, but for the SEL metric instead of LAmax. The predictions for SEL are slightly better, with a difference in the means of the predicted and measured distributions of approximately 2.6 dB (underprediction by AEDT-AE). The AEDT-AE SEL histogram appears highly similar to that for LAmax but has less accentuated multimodality. This finding makes sense, given the integrated nature of the noise metric.

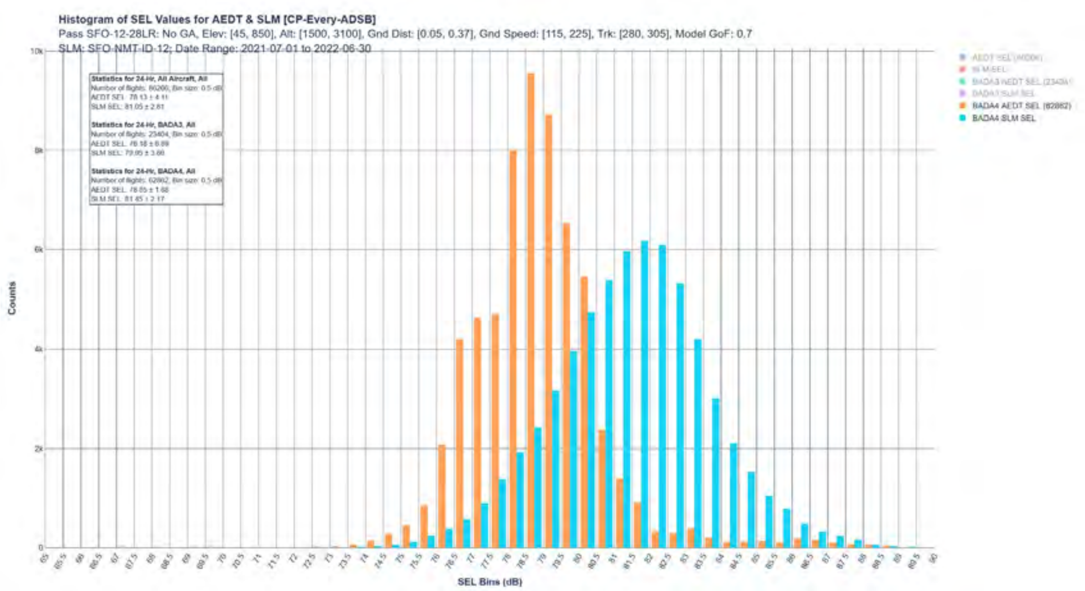

Figure 5. Histogram with the SEL values from AEDT-AE predictions (orange) and SLM measurements (light blue) at the SFO-NMT-12 location. SEL data are binned into 0.5-dB intervals. **Preliminary data: please do not cite or quote.**

Figure 6 displays the differences between the predicted (AEDT-AE) and measured (SLM) noise levels for both LAmax (in orange) and SEL (in light blue). Again, these results are for the same data set containing only BADA4 aircraft. Regardless of the metric, these preliminary results indicate a consistent underprediction of −3.0 dB (with a standard deviation of 2.3 dB) for LAmax and −2.6 dB (with a standard deviation of 2.1 dB) for SEL. These results are consistent in both trends and value with the results that we presented in last year's annual report, which were based on a far smaller data set (30 days in the summer vs. 12 months).

Finally, Figure 7 displays our calculations for the DNLs for both the predicted (AEDT-AE) and measured (SLM) noise levels. On the basis of an entire 12-month period of measurements, using AEDT-AE, we predicted a DNL at this location of 58.1 dB, as compared with the measured DNL of 60.1 dB, thus indicating an underprediction of DNL 2.0 dB. Notably, AEDT-AE is not approved for regulatory use, and these results remain preliminary. Some outliers in the plot correspond to the accounting of flights during daylight savings days and an outage for one of our ADS-B collectors. These results will later be compared with the same DNL predictions and measurements at a location farther from the airport (SIDBY). Although additional work will be conducted to further refine our estimates of the differences, we expected that AEDT-AE would do a significantly better job at a location close to the airport, but a DNL 2 dB difference in absolute value over an entire 12-month period is considered significant.

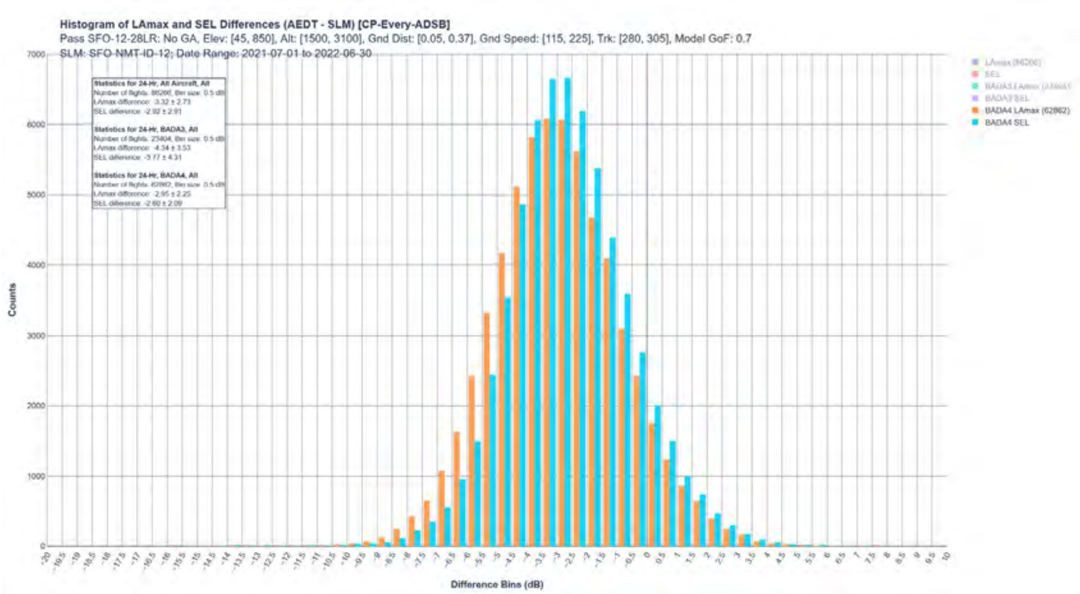

Figure 6. Histograms with the LAmax (orange) and SEL (light blue) differences between AEDT-AE predictions and SLM measurements at the SFO-NMT-12 location. A negative value indicates underprediction by AEDT-AE. Noise level difference data are binned into 0.5-dB intervals**. Preliminary data: do not cite or quote.**

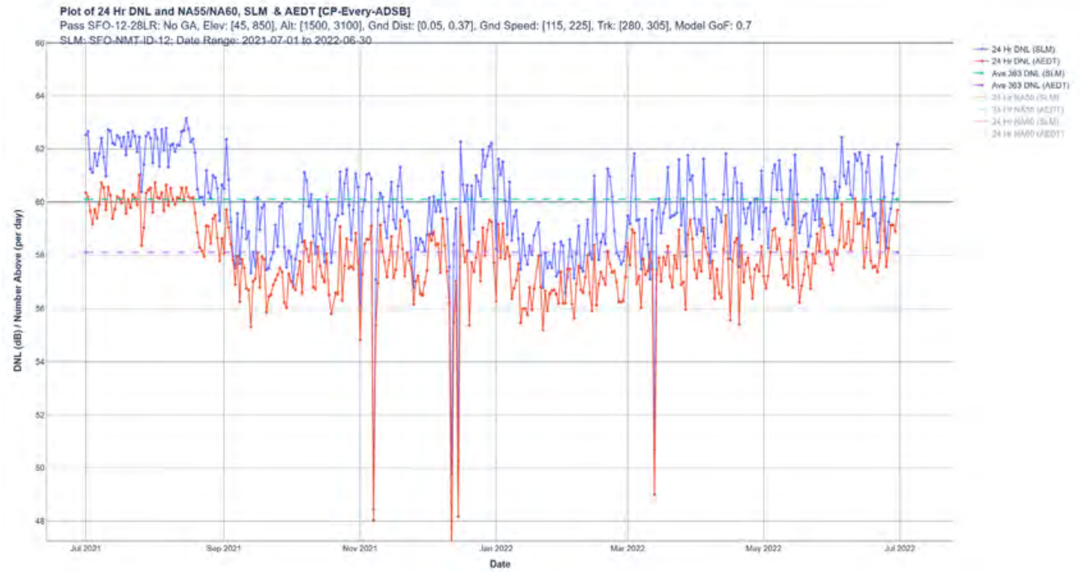

Figure 7. Daily calculated (red) and measured (blue) DNL (in dB) at the SFO-NMT-12 location. The SLM DNL is 60.1 dB, whereas the AEDT-AE-predicted DNL is 58.1 dB. **Preliminary data: do not cite or quote**.

Preliminary Results for the SIDBY Location

Preliminary observations resulting from processing of the data predicted and collected at the SIDBY SLM are presented below. Notably, the data set at SFO-NMT-12 contains additional flights, because it includes not only aircraft approaching via the SERFR, BDEGA, and PIRAT routes, but also all aircraft arriving from the east through the DYAMD route. Nonetheless, the total data set still contains 64,885 flights over the same 12-month period spanning July 1, 2021 to June 30, 2022.

Figures 8 and 9 show coarse-grained histograms (in the sense that they contain all the aircraft of all types over a 12-month period) for both LAmax and SEL for the 17,046 flights considered in this study (starting from 64,885 flights but retaining only those passing all of our quality checks). The data have been binned in 0.5-dB intervals and represent the actual noise metric values (for each individual flight) for both AEDT-AE predictions (in orange) and SLM measurements (in light blue), after removal of background noise. The data set includes only aircraft/flights that can be modeled with BADA4. Several observations can be made from these two figures, which are similar in many respects to the observations made for the SFO-NMT-12 location. First, the variability and multimodality of the AEDT-AE-predicted data remain significant, albeit somewhat reduced when compared to SFO-NMT-12, and it is absent in the SLM measurements, which appear to showcase a Gaussian-like distribution for the aircraft observed. Of note, the Gaussian-like distribution for the measured noise levels is not as smooth at what we saw at SFO-NMT-12, but the slight noisiness in the results is caused by the fact that the number of flights considered in the histograms is approximately one-quarter the number of flights used in SFO-NMT-12. The AEDT-AE prediction distribution remains multimodal, and the provenance of each bar in the histogram from different aircraft types and classes is indicated. Close examination and data analysis based on individual classes of aircraft showed that the predicted histogram peak at approximately 55 dB LAmax is a merger of both larger regional jets and single-aisle aircraft (with those aircraft contained in the 52–60 dB range), whereas the twin aisle and large twin aisle categories are seen at higher noise levels.

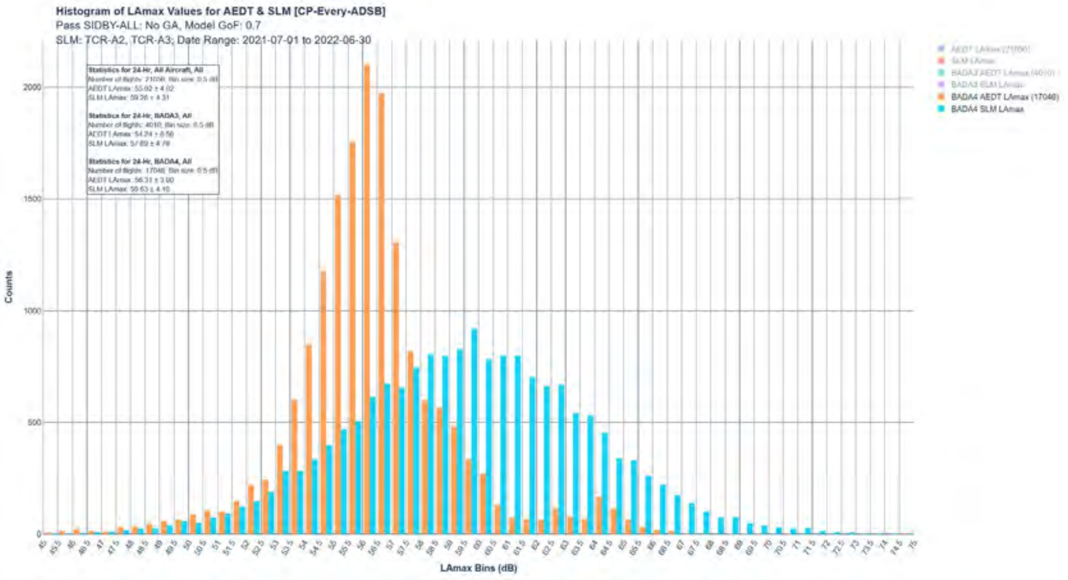

Figure 8. Histogram with the LAmax values from AEDT-AE predictions (orange) and SLM measurements (light blue) at the SIDBY location. LAmax data are binned into 0.5-dB intervals. **Preliminary data: do not cite or quote**.

At this SLM location, which has combinations of aircraft trajectories that are highly concentrated (as with those arriving along the SERFR route) and highly diffuse (as with those arriving along the BDEGA and PIRAT routes), substantial variability in altitudes, airspeeds, and distances at the PCA is observed. Therefore, the measured histogram is rather broad and has a large standard deviation. This natural variability, together with variations in atmospheric, turbulence, and weather conditions, result in a very smooth distribution of noise events. The difference in the means of the AEDT-AE and SLM distributions is approximately −3.3 dB (underprediction by AEDT-AE), with a very large standard deviation for LAmax of 3.5 dB.

Figure 9 shows similar results for the exact same data set, but for the SEL metric instead of LAmax. The predictions for SEL are significantly better, with a difference in the means of the predicted and measured distributions of approximately −1.7 dB (underprediction by AEDT-AE) and a very large standard deviation of 3.2 dB. The AEDT-AE SEL histogram is highly similar to that for LAmax but has less accentuated multimodality, given the integrated nature of the noise metric.

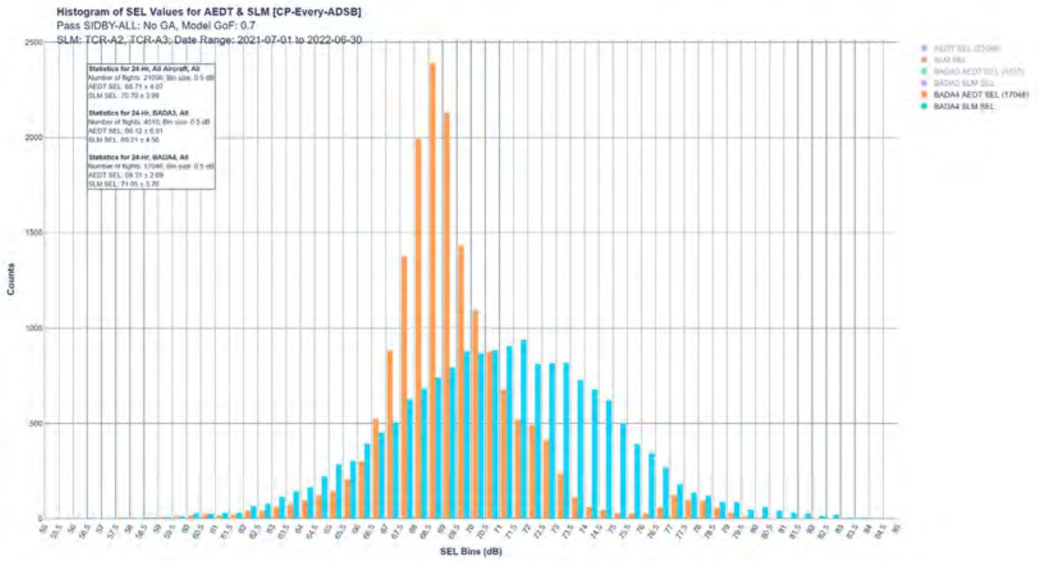

Figure 9. Histogram with the SEL values from AEDT-AE predictions (orange) and SLM measurements (light blue) at the SIDBY location. SEL data are binned into 0.5-dB intervals. **Preliminary data: do not cite or quote**.

Figure 10 displays the differences between the predicted (AEDT-AE) and measured (SLM) noise levels for both LAmax (in orange) and SEL (in light blue). Again, these results are for the same data set containing only BADA4 aircraft. Regardless of the metric, these preliminary results indicate a consistent underprediction of −3.3 dB (with a standard deviation of 3.5 dB) for LAmax and −1.7 dB (with a standard deviation of 3.2 dB) for SEL. These results are consistent, in both trends and values, with the results that we presented in last year's annual report, on the basis of a far smaller data set (30 days in the summer vs. 12 months).

Finally, Figure 11 displays our calculations for the DNLs for both the predicted (AEDT-AE) and measured (SLM) noise levels. On the basis of an entire 12-month period of measurements, using AEDT-AE, we are able to predict using AEDT-AE, a DNL at this location of 43.9 dB, as compared with the measured DNL of 46 dB. The underprediction of DNL by 2.0 dB was very similar in magnitude to the underprediction observed much closer to the airport at SFO-NMT-12. It must be noted that AEDT-AE is not approved for regulatory use and that these results are still preliminary. The outliers in the plot correspond to the accounting of flights during daylight savings days. In comparison with the same DNL predictions and measurements at the location closer to the airport (SFO-NMT-12), we do observe that AEDT-AE predictions are slightly better for SEL, but nearly identical for both LAmax and DNL. While additional work will be conducted to further refine our estimates of the differences, and as we mentioned earlier, our expectation was that AEDT-AE would do a significantly better job at a location close to the airport; however, this conjecture was not borne out by the data. We must be careful and restrict our preliminary conclusions to date to arrivals into SFO only. We expect that the predictions for departures will significantly improve, and we are currently working on those results.

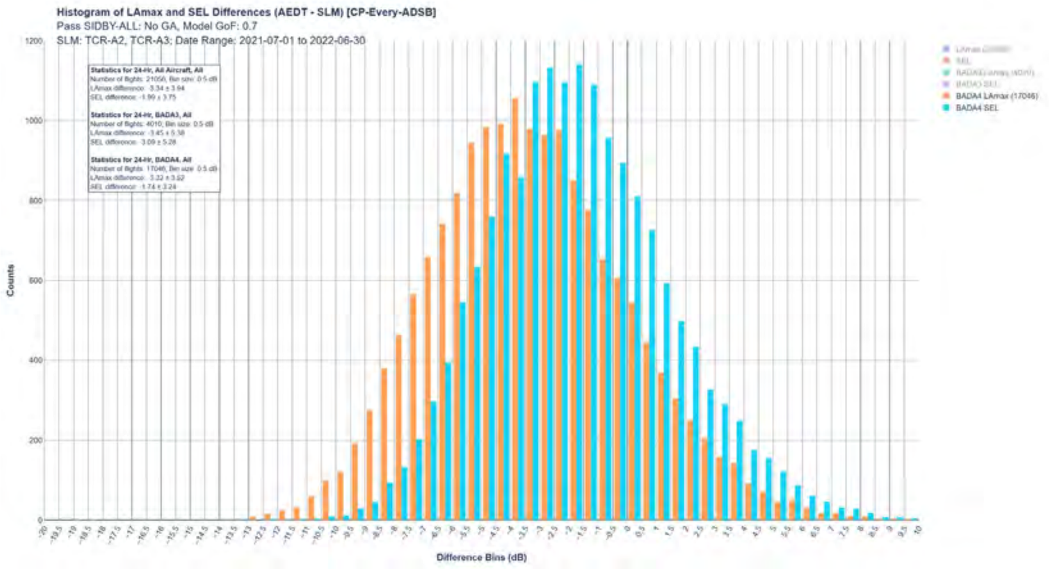

Figure 10. Histograms showing the LAmax (orange) and SEL (light blue) differences between AEDT-AE predictions and SLM measurements at the SIDBY location. A negative value indicates an underprediction by AEDT-AE. Noise level difference data are binned into 0.5-dB intervals. **Preliminary data: do not cite or quote.**

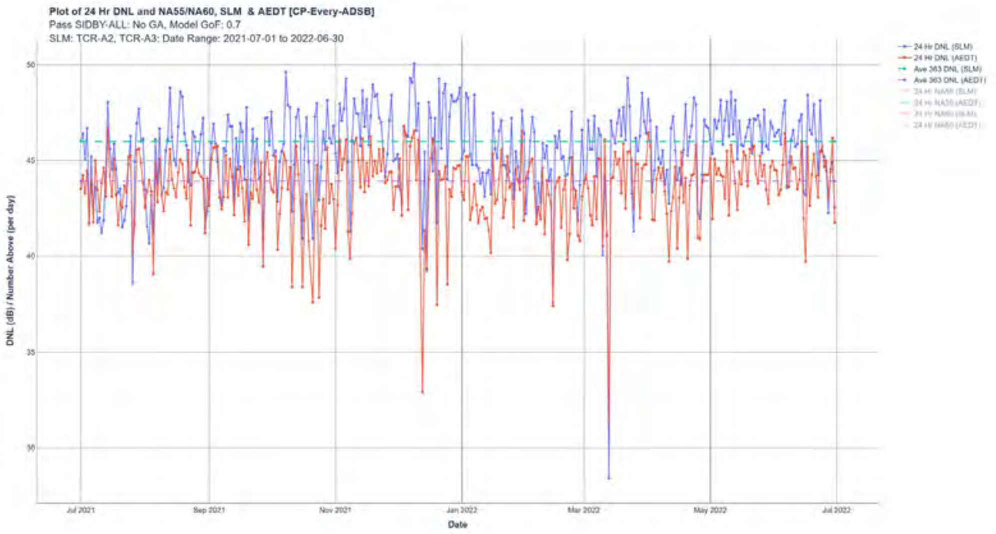

Figure 11. Daily calculated (red) and measured (blue) DNL values (in dB) at the SIDBY location. The SLM DNL value is 60.1 dB, whereas the AEDT-AE-predicted DNL value is 58.1 dB. **Preliminary data: do not cite or quote.**

Impact of Calibrated Airspeed on Noise Predictions

For aircraft noise models to provide useful information for both community impact assessments and airspace redesign, the models must faithfully represent the level of noise produced by aircraft overflights in both areas near the airport, where the noise levels can be substantial (DNL > 65 dB), and in areas farther from the airport, where the noise levels are typically lower (DNL ~50 dB). A number of recent studies, including some by the authors, have attempted to assess the accuracy of the SAE-AIR-1845 aircraft noise model used by AEDT-AE, which was originally intended for use only in the vicinity of airports. Giladi et al. (2020), for example, have conducted assessments of the predicted vs. measured noise and have found that "the AEDT model underestimates noise levels, sometimes considerably, by 4 to 7 dB(A) in the SEL metric, even when using an accurate flight path for its input." The findings suggest that "aircraft noise model validation should be separated into four cases; takeoffs and landings, and for each operation, a different approach should be used for close and far [SLMs]." The authors further suggest that improvements in the predictive quality of the models might also "involve correction of at least the NPD tables, as well as takeoff profiles." Huyhn et al. have used techniques combining predictions from the NASA Aircraft Noise Prediction Program (ANOPP, and its most recent version ANOPP2) and measurements to assess the potential of arrival procedures flying delayed deceleration approaches to minimize the noise observed on the ground. The authors have found that "delayed deceleration approaches correlated with monitor readings with lower noise levels of an average of 3–6 dB SEL compared to early deceleration approaches across different aircraft types," in addition to observing that substantial effort and sophistication was necessary, beyond standard noise models, to match the measurement data.

The data sets collected, particularly that for SFO-NMT-12, as described earlier, allowed us to examine a key weakness of the noise model used in AEDT. This weakness is structural: the noise levels are based on NPD curves and were developed for areas of the flight paths where engine noise was the dominant noise source; however, this dominance is no longer the case in many arrivals operations. As shown in Figure 12 (adapted from AIAA 2011-2854) for aircraft in approach situations, the contributions from engine and aircraft noise can be highly similar, and therefore a noise model that does not account for both sources of noise on arrivals can underestimate the overall predicted noise levels, particularly farther from the airport, such as at the SIDBY location.

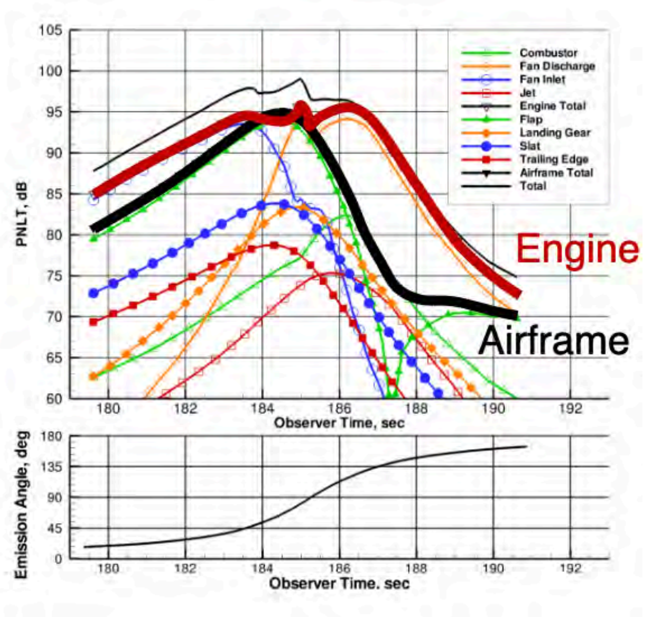

Figure 12. ANOPP2 component noise predictions for conventional aircraft in approach. Adapted from Lopes & Burley, AIAA 2011–2854, 17th AIAA/CEAS Aeroacoustics Conference.

Using the data collected at SFO-NMT-12 for approaches into SFO runway 28L alone, we plotted the predicted (AEDT-AE, in blue) and measured (SLM, in red) noise data, as a function of calibrated airspeed (CAS) from the ADS-B feed (Figure 13). We expected that the noise levels would increase with airspeed, because of the contribution from airframe noise scales with the value of the airspeed. Our expectation was indeed confirmed by the trendline from the measurements, wherein an increase of approximately 0.4 dB for every 10-knot increase in CAS was observed. The trend for the predictions from AEDT-AE was counterintuitive: the trend line predicted an average decrease of 0.3 dB for every 10-knot increase in CAS. This opposite trend in the noise levels with CAS might contribute to the overall underestimation of noise levels by AEDT-AE.

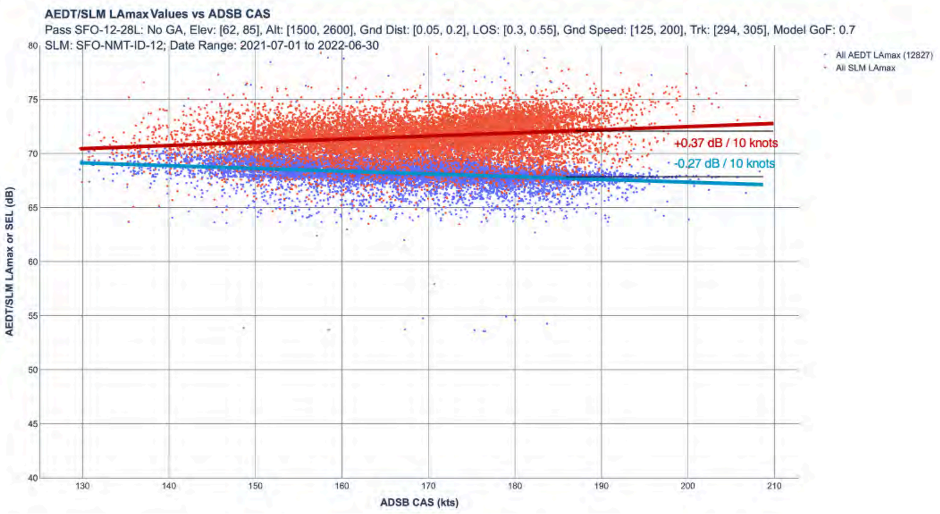

Figure 13. Predicted (AEDT-AE) in red and measured (SLM) LAmax noise levels in blue at the SFO-NMT-12 location, as a function of CAS. Only single-aisle aircraft landing at runway 28L are included in this data set of 12,827 flights.

Preliminary Conclusions

Disclaimers: The results in this section represent our conclusions resulting from the work conducted during the current period of performance (October 1, 2021 to September 30, 2022). These results represent our first attempt at yearly comparisons between AEDT predictions and experimental noise data and variations with CAS. As such, and until improved results are published in a peer-reviewed journal (as of February 2023, we have completed substantially more comparisons than presented in this annual report), the results presented here should be considered preliminary. They provide an indication of our main observations but lack the level of confidence required to make sufficiently strong statements. Moreover, while AEDT is the tool used for regulatory purposes in the United States, we used a version of AEDT that we call AEDT-AE, which uses the collected aircraft track data, BADA4 performance models, and altitude and speed controls to complete simulations (BADA, n.d.). We do not claim that AEDT-AE has any regulatory value.

Our preliminary conclusions from the work presented in this annual report on our early comparisons between AEDT-AE predictions and SLM measurements is summarized in the following statements. Additional work conducted since the beginning of October 2022 will further strengthen these conclusions, but the overall preliminary findings still stand, and minor changes have been made after additional scrutiny. The conclusions of these studies will be considered final after peer-reviewed publications become available in the summer of 2023.

- Preliminary investigations indicated an underestimation of noise predictions for individual-event sound levels on arrival operations to SFO by ~1.7–3.3 dB (mean values) for both LAmax and SEL metrics, regardless of the DNLs at the location of the noise monitoring station. We arrived at this preliminary conclusion after examining approximately 135,000 flights and devoting substantial effort to retaining only a subset of flights whose associated noise events were of the highest quality and represented aircraft activity only.
- BADA4 aircraft modeling results in significant improvement in noise predictions over BADA3 aircraft. In the work presented here, we focused on BADA4 modeling, as the only way for AEDT-AE to incorporate altitude and speed controls (instead of using standard profiles for altitude and airspeed in modeling aircraft trajectories by using BADA3). This improvement is likely to be related to the better aircraft performance model available in BADA4 (for some aircraft types only), thus leading to a better estimation of the engine noise component. Further comparisons across multiple aircraft classes (with BADA3 vs. BADA4) have recently been conducted and will be reported at a later time. The new observations strengthen this preliminary conclusion.
- The variability in the difference between measurement and prediction was high, with a standard deviation of ~3–5 dB. We believe that this important area warrants further investigation to ascertain the main causes of this high variability.

- The SAE-AIR-1845 model used in AEDT-AE does not properly account for the variation in noise resulting from changes in CAS. This aspect is a shortcoming of the noise prediction method for arrivals operations and is not meant as a criticism of the existing noise model which, in its original publication, recognized the conditions for its proper use and situations in which the model would fail to provide accurate predictions.
- The expectation of AEDT's improved accuracy in noise estimates in higher DNL noise areas did not appear to be borne out by the data in the two arrival locations examined. As our study progresses, we intend to verify this preliminary conclusion at several other locations to ascertain whether our initial observations might change. This observation has been restricted to arrivals operations, whereas we expect departure operations to yield better results.
- AEDT predictions for aggregate noise metrics (not individual flights) still show significant differences of around DNL 2.0 dB regardless of the location of the noise monitoring station and the DNL values of those locations. Our continued work to strengthen this conclusion has not yet resulted in any modifications to the statements being made in this annual report.

Major Accomplishments

- Completed a completely new infrastructure for ASCENT 53/MONA that has been shown to scale to the types of data collection and analysis expected for a complex metroplex, such as the Bay Area
- Demonstrated full automation of the AEDT analysis pipeline and of the noise prediction/measurement comparisons for arbitrarily large data sets
- Demonstrated the use of the ASCENT 53/MONA infrastructure to simulate (and compare) flights arriving at runways 28L/R at SFO over a period of 12 months (more than 135,000 individual flights); decreased the computational time required to complete such studies to approximately 2 days
- Drew preliminary conclusions from the comparisons between AEDT predictions and SLM measurements at two locations (SIDBY and SFO-NMT-12) under the arrival routes to SFO
- Concluded an investigation of the trends of AEDT-AE noise prediction methods with CAS, and reported our results.

Publications

Jackson, D. C., Rindfleisch, T. C., & Alonso, J. J. (2021). A system for measurement and analysis of aircraft noise impacts. *The 9th OpenSky Symposium*, 6. https://doi.org/10.3390/engproc2021013006

Outreach Efforts

Over the past few months, we have developed a closer relationship with SFO and the technical leads at EnviroSuite, which deploys, monitors, and makes available the noise data at approximately 40 locations in the Bay Area. We have hosted technical interactions with both groups on various topics including the filtering techniques for non-aircraft noise that we have developed in ASCENT 53. These outreach efforts have resulted in the sharing of noise data at many locations, including historical data sets, and a commitment to continue to share data as they are acquired in the future.

Awards

None.

Student Involvement

Several undergraduate and graduate students are/have been part of our team during this past year. Their names and areas of responsibility are listed at the beginning of this document. Several students graduated during the current period of performance, but we have enlisted new students to continue the work. Their contributions are acknowledged here, because the project would not have advanced to this extent without them.

Plans for Next Period

We intend to complete all three tasks in our Statement of Work as planned. In addition to the completion of all milestones, the release of appropriate parts of the ASCENT 53/MONA project and the demonstration of various capabilities through participation in aircraft noise related meetings/conferences are also envisioned. Two manuscripts detailing our efforts are under preparation and will be submitted to archival journals for review in March 2023. The expected publication is in the Fall of 2023.

References

Next generation air transportation system (Nextgen) | Federal Aviation Administration. (n.d.). Retrieved May 18, 2023, from https://www.faa.gov/nextgen

PiAware—Ads-b and MLAT receiver. (n.d.). FlightAware. Retrieved May 18, 2023, from http://flightaware.com/adsb/piaware/

Apache Kafka. (n.d.). Apache Kafka. Retrieved May 18, 2023, from https://kafka.apache.org/

Jetdev. (n.d.). *Jetvision Webshop*. Retrieved May 18, 2023, from https://webshop.jetvision.de/

Convergence Instruments. (n.d.) Sound Level Meters. Retrieved November 7, 2021, from https://dev.convergenceinstruments.com/pc/sound-level-meter-data-loggers/

AeroAPI® Flight Tracking and Flight Status api. (n.d.). FlightAware. Retrieved May 18, 2023, from http://flightaware.com/commercial/aeroapi/

FAA System Wide Information Management (SWIM). (n.d.). Retrieved November 7, 2021, from https://www.faa.gov/air_traffic/technology/swim/

FAA Aircraft Registry. (n.d.). Retrieved November 7, 2021, from https://www.faa.gov/licenses_certificates/aircraft_certification/aircraft_registry/

OpenSky Aircraft Metadata Database. (n.d.). Retrieved November 7, 2021, from https://opensky-network.org/datasets/metadata/

Coded Instrument Flight Procedures (CIFP). FAA. (n.d.). Retrieved November 7, 2021, from https://www.faa.gov/air_traffic/flight_info/aeronav/digital_products/cifp/

Benjamin, S. G., Weygandt, S. S., Brown, J. M., Hu, M., Alexander, C. R., Smirnova, T. G., Olson, J. B., James, E. P., Dowell, D. C., Grell, G. A., Lin, H., Peckham, S. E., Smith, T. L., Moninger, W. R., Kenyon, J. S., & Manikin, G. S. (2016). A north American hourly assimilation and model forecast cycle: The rapid refresh. *Monthly Weather Review*, *144*(4), 1669–1694. https://doi.org/10.1175/MWR-D-15-0242.1

Wynnyk, C. M. (2012). Wind analysis in aviation applications. *2012 IEEE/AIAA 31st Digital Avionics Systems Conference (DASC)*, 5C2-1-5C2-10. https://doi.org/10.1109/DASC.2012.6382366

Group, P. G. D. (2023, May 18). *Postgresql*. PostgreSQL. https://www.postgresql.org/

Postgis. (n.d.). PostGIS. Retrieved May 18, 2023, from https://postgis.net/

Time-series data simplified. (n.d.). Retrieved May 18, 2023, from https://www.timescale.com/

Harding, M. & Ferrier, D. (2014). *Using Post Analysis of a Noise Sample Stream in place of Noise Monitor Based Thresholds in the Detection of Aircraft Noise*. INTER-NOISE and NOISE-CON Congress and Conference Proceedings. Institute of Noise Control Engineering, Melbourne, Australia.

Giladi, R. (2020). Real-time identification of aircraft sound events. *Transportation Research Part D: Transport and Environment*, *87*, 102527. https://doi.org/10.1016/j.trd.2020.102527

H3 | H3: Hexagonal Hierarchical Geospatial Indexing System. (n.d.). Retrieved May 18, 2023, from https://h3geo.org/

FAA: FAA Aviation Environmental Design Tool (AEDT). (n.d.). Retrieved May 18, 2023, from https://aedt.faa.gov/

Giladi, R., & Menachi, E. (2020). Validating aircraft noise models. *8th OpenSky Symposium 2020*, 12. https://doi.org/10.3390/proceedings2020059012

SQL server 2019 | Microsoft. (2019). Retrieved May 18, 2023, from https://www.microsoft.com/en-us/sql-server/sql-server-2019

ANP—Eurocontrol Experimental Centre. (n.d.). Retrieved May 18, 2023, from https://www.aircraftnoisemodel.org/

Base of aircraft data (BADA). EUROCONTROL Experiemental Center. (n.d.). Retrieved May 18, 2023, from https://www.eurocontrol.int/model/bada

Douglas, D. H., & Peucker, T. K. (1973). Algorithms for the reduction of the number of points required to represent a digitized line or its caricature. *Cartographica: The International Journal for Geographic Information and Geovisualization*, *10*(2), 112–122. https://doi.org/10.3138/FM57-6770-U75U-7727

Ramer, U. (1972). An iterative procedure for the polygonal approximation of plane curves. *Computer Graphics and Image Processing*, *1*(3), 244–256. https://doi.org/10.1016/S0146-664X(72)80017-0

deck.gl: WebGL-powered Visualization Framework for Large-scale Datasets. Retrieved May 18, 2023, from https://deck.gl/