Project 043 Noise-Power-Distance Re-Evaluation

Georgia Institute of Technology

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- Tasks:
    1. Year 3 Task 1: Investigate the impact of frequency content on standard noise-power-distance (NPD) curves through a sensitivity study of weather effects in the Aviation Environmental Design Tool (AEDT).
    2. Year 3 Task 2: Investigate the impact of frequency content on NPD + configuration (NPD+C) data by utilizing NASA's Aircraft Noise Prediction Program (ANOPP) tool.
    3. Year 3 Task 3: Perform a validation with noise data in AEDT.
    4. Year 4 Task 1: Development and Testing of NPD+C Correction Function.
    - Other Work Supporting Tasks: Development of AEDT Tester.

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Project Overview

The standard technique for evaluating fleet noise is to estimate flight procedure source noise using noise-power-distance (NPD) curves. Noise calculations within the Aviation Environmental Design Tool (AEDT) rely on NPD curves provided by aircraft manufacturers. This dataset reflects representative aircraft categories at set power levels and aircraft configurations. Noise levels are obtained as a function of slant distance via spherical spreading through a standard atmosphere, and other correction factors are applied to obtain the desired sound field metrics at the location of the receiver. The current NPD model does not consider the aircraft configuration (e.g., flap settings) or alternative flight procedures being implemented. These factors are important, as the noise characteristics of an aircraft depend on thrust, aircraft speed, and airframe configuration, among other contributing factors such as ambient conditions. The outcome of this research is an approach based on the suggested NPD + configuration (NPD+C) format, which will enable more accurate noise predictions due to its inclusion of aircraft configuration and speed changes.

This project is currently in its fourth year and finished up the third-year effort in the last calendar year. During the third year, this work focused on two main topics. First, prior work was extended to examine the impact of NPD spectral (frequency) content on noise contours. This first focus was divided into two aspects: 1) the manner in which the spectral data are used within AEDT while all other parameters are held constant, and 2) the manner in which the noise contours change when utilizing spectral data generated from the Environmental Design Space (EDS) in a fashion similar to that of the NPD+C approach. Second, the NPD+C approach will be validated using available aircraft operation and airport noise monitoring data. A brief description of the prior work is provided for reference.

Year 3 Task 1– Investigate the Impact of Frequency Content on Standard NPD Curves

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This task was completed in the previous year. Please refer to the 2019 Annual Report for this project for details.

Year 3 Task 2 – Investigate the Impact of Frequency Content on NPD+C Data

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Objective(s)

This Task extends the work which was completed under Year 3 Task 1. Test cases from Year 3 Task 1 are re-executed using NPD+C data with spectral content to include configuration information (flight speed, flap setting, and gear setting). The AEDT sensitivity study will be repeated, and the results will be compared to those obtained using the standard NPD approach. Changes to the noise grid and contours will be analyzed to determine whether the increased complexity due to the inclusion of configuration-dependent spectral data is outweighed by the increased fidelity of community noise predictions for typical weather at the airport.

Research Approach

The overall research approach can be summarized in the following steps:

1. Selection of aircraft and their ANOPP simulations to obtain NPD+C data.
2. Selection of airport and weather conditions for simulations.
3. Simulations in AEDT to obtain noise metrics for each combination of spectral condition and weather condition for all selected aircraft.
4. Comparison of noise grids and conclusions.

The first step involved in this Task was the selection of aircraft for consideration. While a large number of aircraft are available in AEDT, only a handful of them have been matched to calibrated models for ANOPP; therefore, the following aircraft were selected for this study: CRJ900ER, 737-700, 737-800, 767-300ER, and 777-200ER. Modeling efforts began with the 737-700, followed by the 767-300ER. The results from these two aircraft were sufficient to provide conclusions for this Task; hence, the other aircraft were not modeled.

Once the aircraft were selected, different configuration and speed settings were identified from the aircraft's default STANDARD Arrival profile in AEDT. These settings were then used in ANOPP to obtain the spectral variation and NPD tables for both aircraft. The spectral datasets obtained for the 737-700 representing the one-third octave band spectrum are shown in Figure 1. The subplot on the left shows the raw spectral data visualized as the spectral correction in dB against frequency in Hz for each configuration and speed setting. The subplot on the right shows the difference of each ANOPP dataset to the AEDT baseline. The labels for the plots refer to the configuration and speed setting. For example, 133_D_F39 refers to a condition of 133 kts airspeed, landing gear extended or "down", and flaps deployed to 39˚. Such a condition would be present in the final approach of the aircraft, immediately preceding the touchdown.

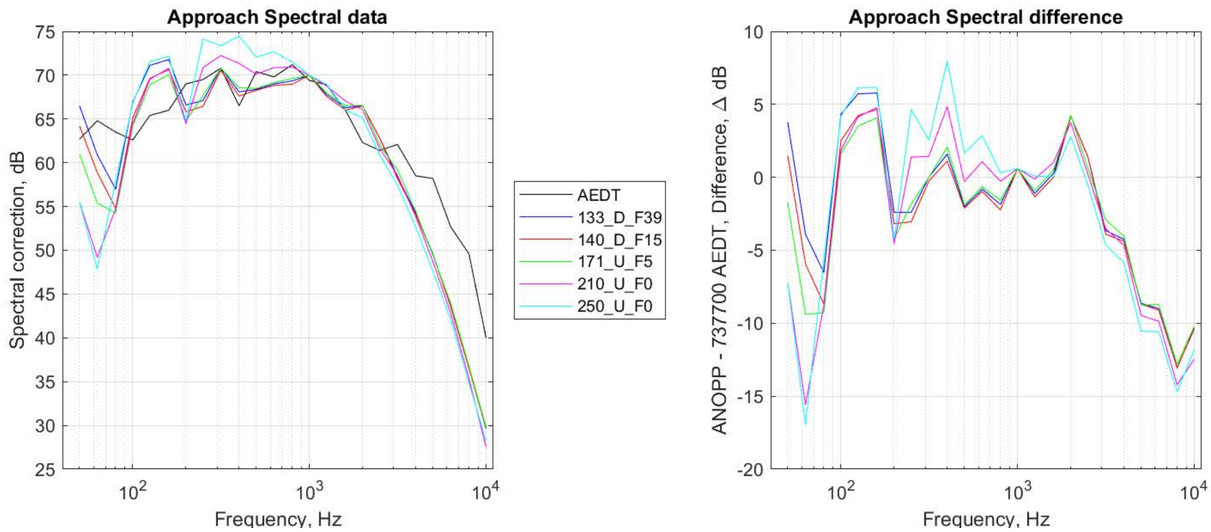


Figure 1. Comparison of spectral data obtained from ANOPP to AEDT baseline for 737-700.

The next step is to setup an AEDT study with the selected airport and the weather conditions. For this Task, Hartsfield-Jackson Atlanta International Airport (KATL) was selected along with 13 weather conditions as shown in Table 1. These weather conditions were selected based on historical weather trends. Additional information for the selection of these conditions is available in the 2019 Annual Report under Task 1.

Table 1. Weather conditions modeled at KATL airport

WEATHER CASE	JOB NUMBER	TEMPERATURE	SEA-LEVEL PRESSURE	STATION PRESSURE	DEW POINT, °F	RELATIVE HUMIDITY, %	WIND SPEED, kts
BASELINE	1	62	1018.02	980.61	50.86	67.65	7.03
TEMP	2	40	1018.02	980.61	30	67.65	7.03
	3	100	1018.02	980.61	87	67.65	7.03
HUMIDITY	4	62	1018.02	980.61	-40.03	1	7.03
	5	62	1018.02	980.61	20.44	20	7.03
	6	62	1018.02	980.61	37.4	40	7.03
	7	62	1018.02	980.61	47.96	60	7.03
	8	62	1018.02	980.61	55.76	80	7.03
	9	62	1018.02	980.61	62	100	7.03
WIND	10	62	1018.02	980.61	50.86	67.65	0
	11	62	1018.02	980.61	50.86	67.65	30
PRESSURE	12	62	985.56	950	50.86	67.65	7.03
	13	62	1141.17	1100	50.86	67.65	7.03

Using these weather definitions, one study in AEDT was created per configuration and speed setting. Each of these studies flew the identical operation for the selected aircraft, namely a fixed-point arrival profile on a straight ground track. If the selected aircraft contained procedural profile definitions, they were converted to fixed-point profiles with the help of performance reports. This step is important because it removes the effect of weather condition on the aircraft trajectory and performance characteristics, while retaining the effect of weather on the noise propagation and spectral correction. For each weather condition, four noise metrics were evaluated on an adequately sized sensor grid surrounding the airport. These four noise metrics were chosen because they represent a mix of both “maximum-level” type metrics and “time-integrated” metrics and are listed below.

1. Sound Exposure Level (SEL/S).
2. Maximum Perceived Noise Level with Tonal corrections (PNLTM/P).
3. Effective Perceived Noise Level (EPNL/E).
4. Maximum A-Weighted Sound Pressure Level (LAMAX/L).

Thus, a total of 6 x 13 x 4 = 312 noise results were obtained. Each noise result consists of a 2D grid of sensors which record the dB level of the noise metric being modeled. Each noise grid was sized as 251 x 41 = 10,291 points spaced 0.1 nmi in both directions. In order to effectively analyze such a large set of results, box plots were created to assess the sensitivities of the noise metrics to the spectral data at the various noise conditions.

One such result is shown in Figure 2. This figure makes use of box and whisker plots to condense a large amount of data from the noise reports into useful information. A boxplot is interpreted as follows;

1. The central point in each box denotes the median.
2. The top and bottom edges of the box indicate the 75th and 25th percentiles.
3. Each whisker extends to 2.7 times the standard deviation of the dataset.
4. All data points outside the whiskers are outliers and are showed as red crosses.

The values being plotted in this figure are the differences in noise dB values over an entire grid; therefore, each box plot represents 10,291 sensors at which this difference was calculated. The noise metric represented by each box plot is labeled on the x-axis as L, P, E, or S. Each collective group of four boxplots represents one weather condition.

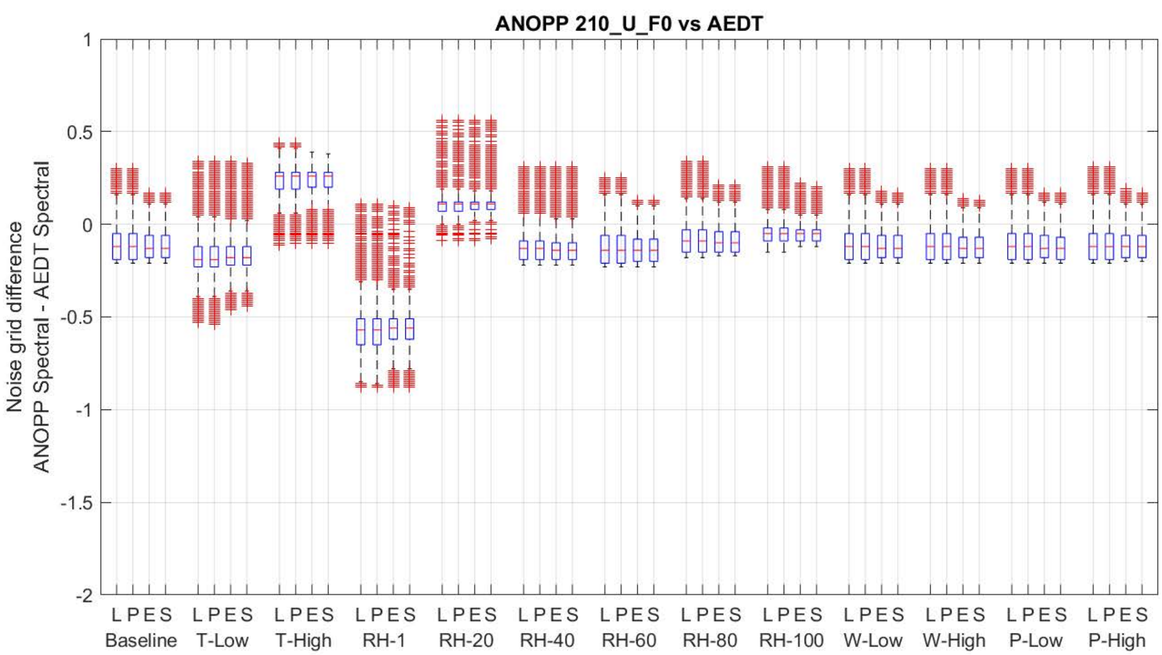


Figure 2. Comparison of noise grids obtained from ANOPP spectral data versus AEDT spectral data, for various weather conditions.

Based on the figure, it is observed that the differences in the noise metrics are very small across all noise metrics and weather conditions for the spectral condition of 210 kts, gear retracted, and flaps at 0°. Similar results were obtained for the other spectral conditions as well for both aircraft. Across all such plots, the RH-1 case was a consistent outlier. This represents a weather condition of 1% relative humidity. In order to further investigate these results, contour plots were made for all four noise metrics at this condition. This collection of contour plots is shown in Figure 3.

For each noise metric, contours are created at various appropriate dB levels. The solid lines represent results from ANOPP spectral, whereas the dashed lines represent results for AEDT spectral. In addition to the contour comparison, the difference in noise levels at each point in the grid is also shown as a heatmap. This visualization aids in the identification of exact regions where the noise level from ANOPP spectral is higher or lower than the AEDT spectral. It is observed that dB differences across the entire grid are limited to ±1 dB, with most regions of the grid well below ±0.5 dB. Additionally, it is also observed that for all four noise metrics, the contours from ANOPP and AEDT spectral are mostly concurrent with each other. Hence, it was observed that the introduction of spectral data from ANOPP did not appreciably change noise grids and contours.

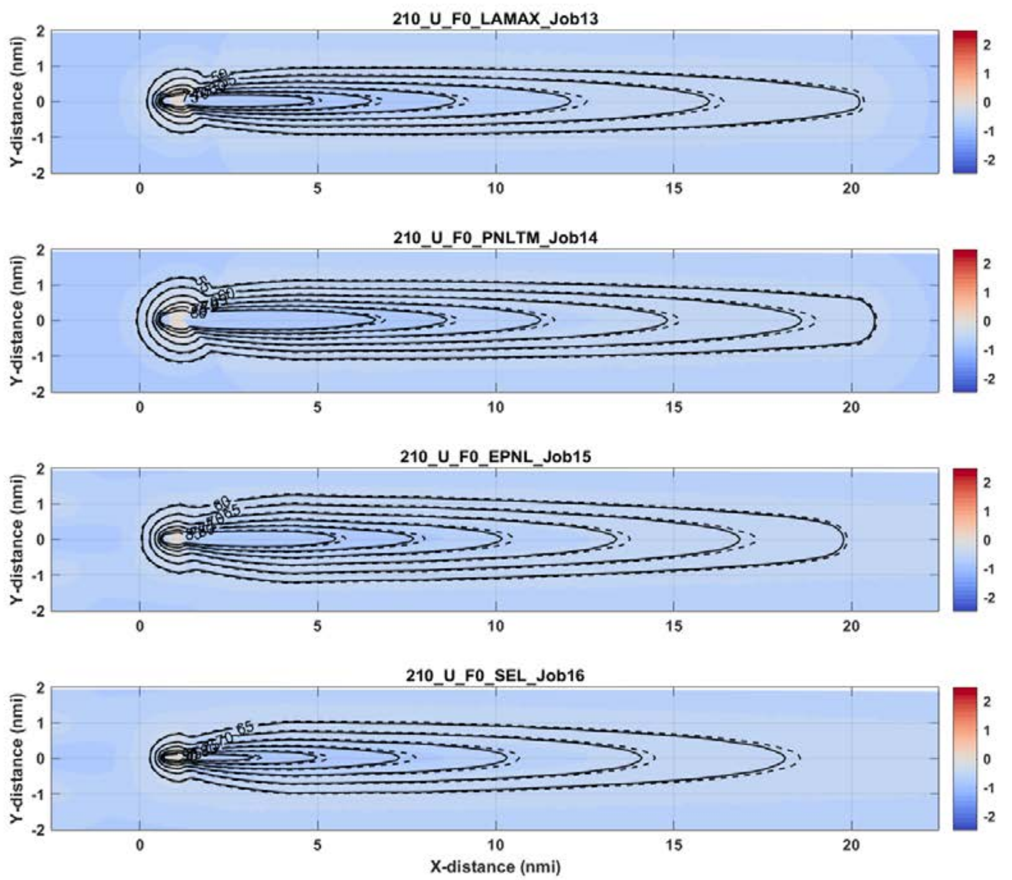


Figure 3. Noise contours comparing ANOPP and AEDT spectral datasets at the 1% relative humidity weather condition.

This observation was consistently present across all 312 noise results; therefore, it was concluded that the inclusion of additional spectral data from ANOPP did not appreciably change noise results when compared to the results for the baseline spectral data in AEDT. The increased complexity due to the inclusion of configuration-dependent spectral data was deemed to not have been outweighed by the increased fidelity of community noise predictions for typical weather at the airport; therefore, implementation of this configuration-dependent spectral data is not recommended.

Milestone

The objective of this Task was completed.

Major Accomplishments

It was found that configuration-dependent spectral data does not appreciably change noise results when compared to the use of baseline AEDT spectral data. As such, no further research is needed for this theme.

Plans for Next Period

This Task is now complete.

Year 3 Task 3 – Validation of AEDT with Noise Data

Georgia Institute of Technology

Objectives

The main objective of this Task was to validate AEDT noise calculations using data obtained from the real-world operations of a commercial airline and noise monitoring data from a partner airport. A secondary objective of this task which served as an enabler for the main objective was modeling real-world airline data (such as radar or flight operations quality assurance (FOQA)) in AEDT using fixed-point profiles in an automated manner.

Research Approach

The overall research approach for this Task is outlined in Figure 4. The process starts with a mapping of airline FOQA data to the noise monitoring data obtained from San Francisco International Airport (SFO) airport. Once this mapping is available, FOQA operations are then modeled in AEDT as fixed-point profiles, flown on user-defined ground tracks. Noise metrics for these operations are then obtained from AEDT at sensor locations which are mapped to the noise monitoring program data at SFO. Finally, the obtained noise metrics can be compared at these noise sensor locations to assess the validity of AEDT models.

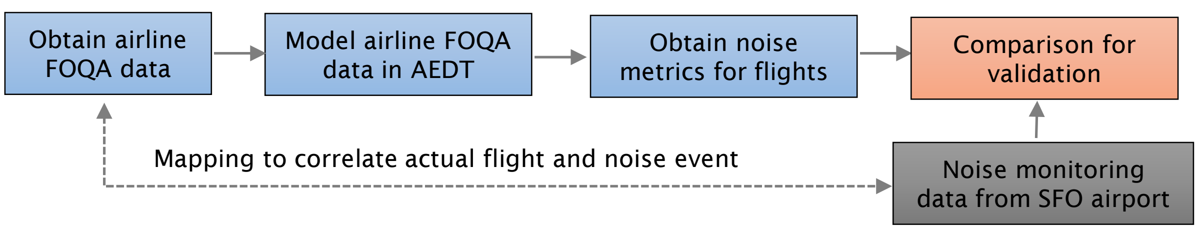


Figure 4. Outline of AEDT noise validation Task.

The real-world validation data sources for this task are FOQA and the SFO noise monitoring program. The FOQA data contains detailed tabulated information obtained from aircraft flight recorders. For each flight, about 600 parameters are available, recorded once per second. Some of the parameters important for this task are height above takeoff/touchdown, airspeeds and groundspeed, geo-location (latitude, longitude), configuration (flaps, slats, landing gear, spoilers), gross weight, and thrust levels. The availability of thrust and weight data is especially important as both are required for the creation of fixed-point profiles in AEDT.

There are several potential sources of difference between AEDT and real-world observations of noise metrics. The use of fixed-point profiles in conjunction with custom ground tracks eliminates the difference associated with aircraft position. Another source of difference is the NPD lookup table which models the noise produced by the aircraft at different speeds and configurations. This was addressed in this task with the use of mode-based NPD lookups in AEDT. Mode-based NPD modeling instructs AEDT to make use of specific NPD sets, instead of a typical lookup based on the aircraft thrust. This allows the user to define multiple NPD sets and associate them with each segment of a fixed-point profile, thereby increasing accuracy of the computed noise metrics. These multiple NPD sets are obtained from ANOPP for each aircraft type under consideration.

In order to effectively perform this Task, many processes had to be automated. This was done primarily through SQL scripts which work on the AEDT backend databases to create studies much faster than through the graphical user interface (GUI).

Additional programming scripts were written to create fixed-point profiles and user defined ground tracks from FOQA datasets.

A dashboard was created in Tableau in order to visualize the large number of flights that were available for modeling, A sample screen from the dashboard, depicting noise sensor locations, flight trajectories, and ground tracks, is shown in Figure 5. This effort was shifted to ASCENT Project 62 in 2020.

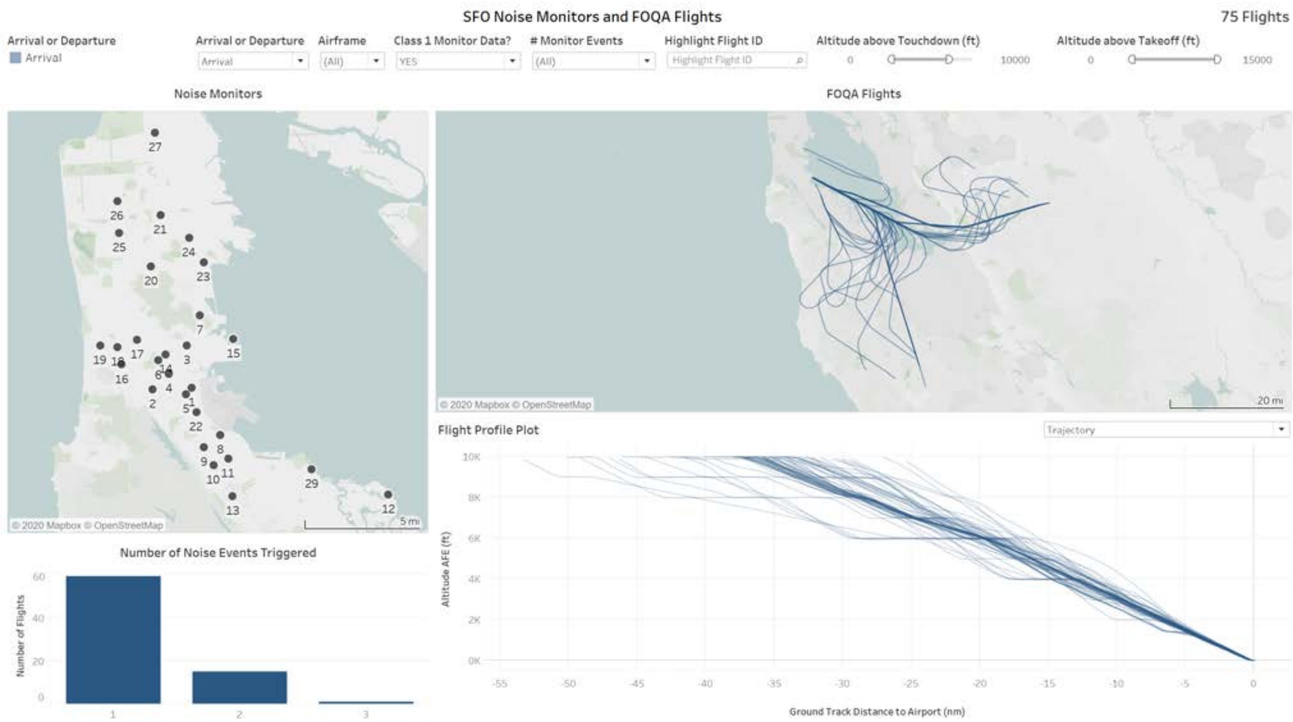


Figure 5. Dashboard created for flight visualization.

Milestone
A process for the validation of noise models based on the component trajectories, weather, ground track, and NPD data was created and implemented for an initial set of flights.

Major Accomplishments
A dashboard was created to visualize noise modeling validation efforts at SFO.

Plans for Next Period
This Task has been migrated to ASCENT Project 62.

Year 4 Task 1 – NPD+C Correction Function
Georgia Institute of Technology

Objectives
The objective of this Task is to create a correction function which will serve to correct an aircraft class' baseline NPD to match a given flight configuration, incorporating flight speed, flap deflection angle, and gear setting.

Research Approach

Overview

Fitting the NPD correction function involved four primary steps. The first was the aircraft class definition, in which the bypass ratios, overall pressure ratios, and rated thrusts were collected for a given aircraft class. Next, these values were used to create a series of engine variants for the aircraft class and were evaluated using the Environmental Design Space (EDS) software to generate engine state tables for use in ANOPP. Following this, ANOPP was used to produce a series of configuration and engine-specific NPDs. The final step of this process was to fit a model to this data, so that the difference between a given configuration and a baseline condition could be predicted. This process is shown in the left column of Figure 6.

Class Definition

The first phase of the correction function modeling process involved defining the scope of the model; specifically, selecting the aircraft and corresponding engines from AEDT for which the model would be based on. A baseline engine was also selected to match the baseline aircraft represented in the ANOPP model. Once this list had been compiled, the engine bypass ratio (BPR), overall pressure ratio (OPR), and sea-level static (SLS) thrust values were collected from AEDT. With this information, the minimum, maximum, and mean values for each parameter could be found, and a full factorial design of experiments (DoE) could be created. This DoE would consist of 27 cases (three BPR values * three OPR values * three thrust values). A 28th case would also be added to account for the baseline engine settings.

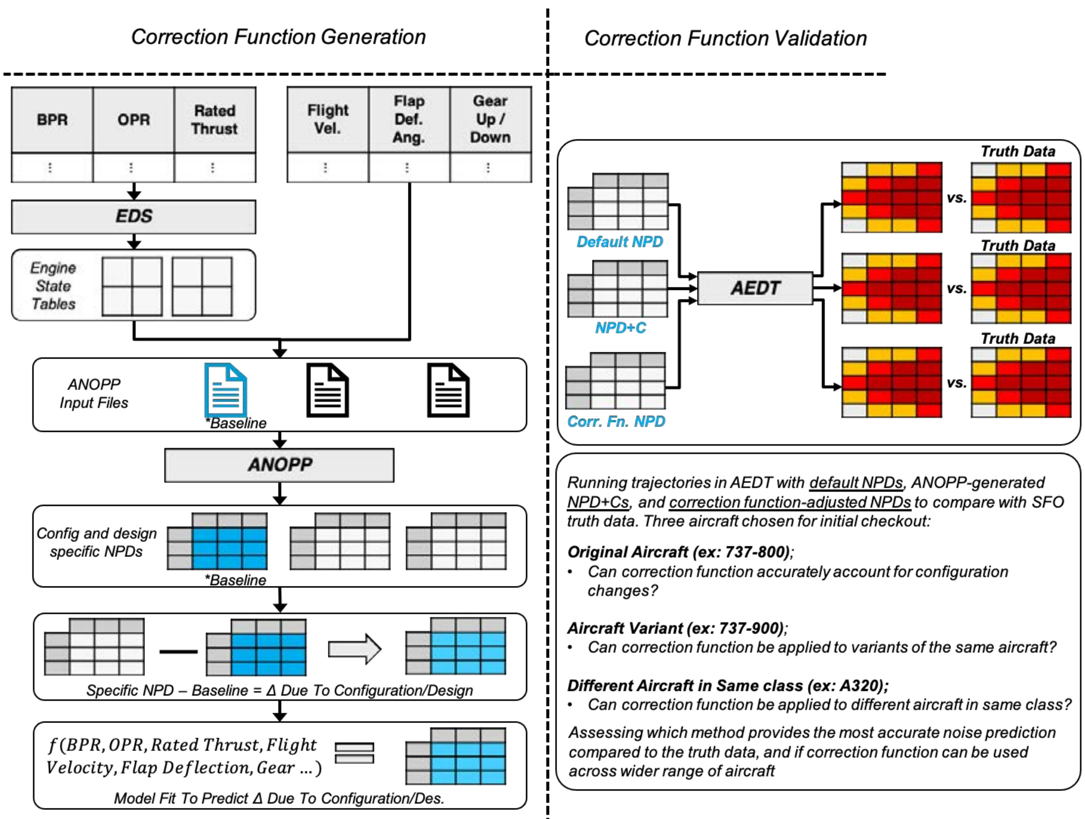


Figure 6. Correction function process.

Environmental Design Space (EDS) Simulations

The next phase of the correction function modeling process involved creating the engine variants to model in EDS. This was done by modifying the baseline EDS engine input of the same class by adjusting the values of the SLS thrust, takeoff thrust, top-of-climb thrust, fan pressure ratio, low-pressure compressor pressure ratio, and high-pressure compressor pressure ratio. Once the values were modified to match the engine settings from the DoE, the simulation was initiated, and the resulting outputs were compiled. These results were then post-processed to extract the specific engine and thrust information needed for use in ANOPP.

ANOPP Simulations
Next, the post-processed EDS data was used to modify aircraft input files for use in ANOPP to generate NPD curves. This consisted of running a given aircraft model with each engine variant at several different flap, speed, and gear settings to generate a full sweep of the configurations that the model would be applied to. Once the ANOPP simulation was completed, the outputs were compiled and transferred to the statistical software package JMP.

Model Fit
The final phase of the correction function modeling process involved creating models within JMP. For a given aircraft class, two models were fit—one with gear down, and one with gear up. The model was fit to the difference between configuration-specific NPDs and the baseline NPD (both coming from the set of ANOPP cases) at the thrust settings corresponding to approach. With this prediction formula, a default NPD could be adjusted to represent different flap, gear, and speed configurations.

150pax Model Fit
When determining the simulation cases to use in creating the correction function, it was found that both the engine parameters and approach NPD for the 100pax model (represented in ANOPP as a 737-700) were close to those of the 150pax model (represented in ANOPP as a 737-800). As such, it was decided to fit a model for both classes simultaneously. Engine variants for the Boeing 737-700/800/900 and the Airbus A318/319/320 were obtained from the equipment database in AEDT, and the minimum and maximum values were found. This domain is shown in Figure 7.

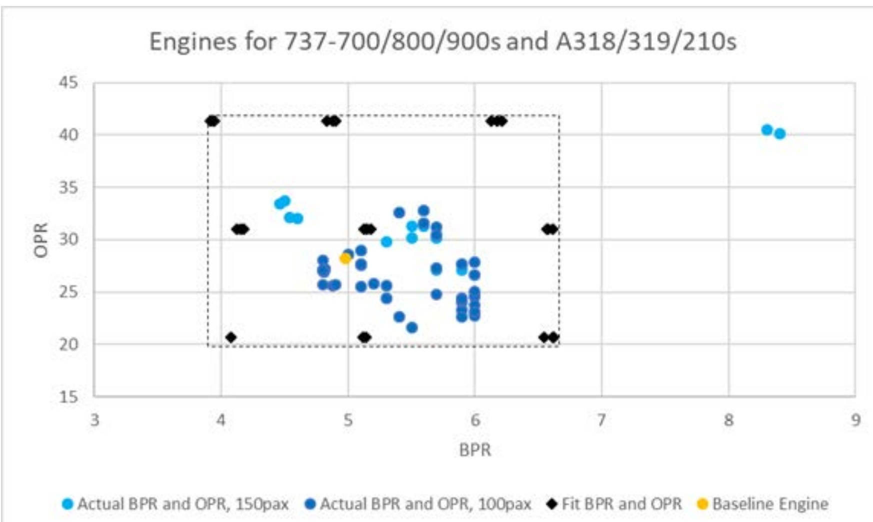


Figure 7. 150pax correction function domain.

Figure 7 shows that the correction function for the 150pax class would be usable for bypass ratios ranging from slightly less than 4 to 6.75, and overall pressure ratios ranging from 20 to 42. To capture all of the relevant rated thrust values, the model was fit using SLS thrust values ranging between 25,350 lbs and 28,400 lbs.

Next, the engines representing the minimum, mean, and maximum OPR, BPR, and rated thrust values were simulated using EDS, and the results postprocessed for use in ANOPP simulations. ANOPP was used to generate the baseline NPD for this aircraft (at a setting of 160 kts, 15° flaps, and gear down) and configuration specific NPDs, with simulations completed at speeds of 130 kts, 160 kts, 190 kts, and 210 kts, flap settings at deflections of 0°, 15°, and 40°, and gear set at both up and down.

The resulting NPDs from the ANOPP cases were post-processed and imported into JMP. Using this tool, two models were fit for approach thrust settings—one with gear up and another with gear down. The models were fit on the difference between the configuration-specific NPDs and the baseline NPD as a function of BPR, OPR, SLS thrust, flap deflection angle, gear setting, aircraft speed, thrust fraction, and distance. Following the creation of the two models, they were tested by comparing the predicted configuration-specific NPDs from the correction function with the original configuration-specific NPDs from ANOPP. The SEL error distributions for this comparison for the gear-down configuration are shown in Figure 8a, and for the gear-up configuration in Figure 8b.

Figure 8 shows that for the gear-down configurations, the error between the baseline NPD corrected for a given configuration and the original configuration-specific NPDs from ANOPP was within the bounds of -1.7 dB and 1.8 dB, with 95% of the cases resulting in an SEL error within -1 dB and 1.1 dB. The model was slightly less accurate for the gear-up configurations, but the SEL error was still within -2.3 dB and 2.4 dB, with 95% of the cases resulting in an SEL error within -1.2 dB and 1.5 dB.

Figure 9 shows the baseline NPD for the 737-800 aircraft. As a demonstration of how the function works, Figure 10 shows the correction function being used to predict the difference between the baseline NPD and the NPD for a flight configuration of 187 kts, flap deflection angle of 1°, and gear-down. Figure 11 is the sum of Figures 9 and 10, reflecting the corrected NPD for the 737-800 in the aforementioned flight configuration.

(a). Gear-down configuration **(b).** Gear-up configuration

Figure 8. SEL error distributions for the gear-down model (left) and gear-up model (right).

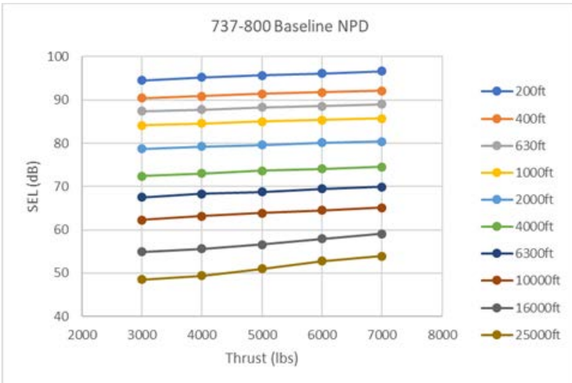


Figure 9. Baseline NPD.

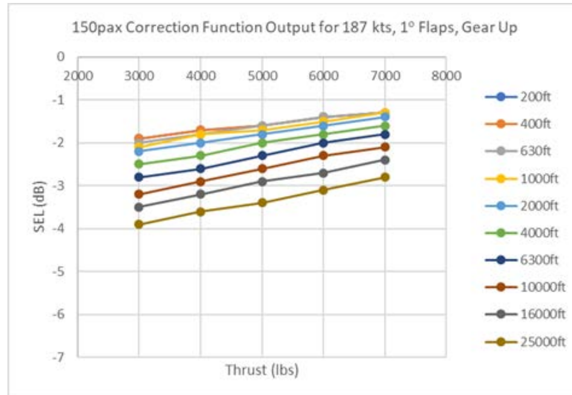


Figure 10. Correction function results for 187 kt, 1°° FDA, gear-down configuration.

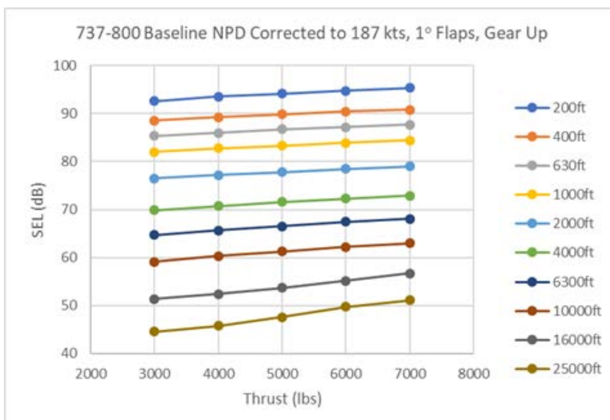


Figure 11. Corrected NPD.

Figures 9–11 illustrate that the correction function model is not creating a new NPD for a given flight configuration; rather, it is predicting the change from the baseline NPD for a given configuration. For each thrust and distance value in the NPD, the correction function predicts the change in SEL from the baseline NPD as a result of the flight configuration. Once the corrected NPD was generated, a series of tests were performed to assess the results.

150pax Model Test

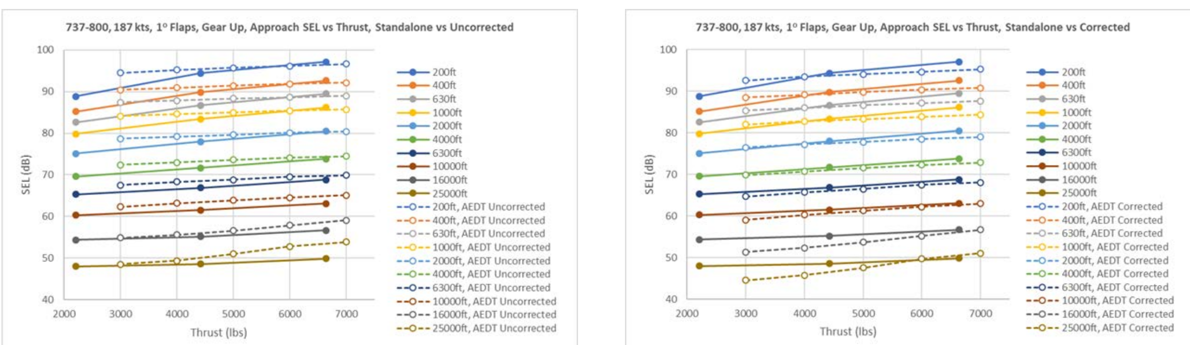
To test the correction function, new ANOPP NPDs were generated for a range of aircraft configurations and compared with the AEDT default NPD with the correction function applied to account for the same configurations. First, the standard approach profiles were collected from AEDT for the baseline aircraft, as shown in Table 2. Although it was understood that the Flap IDs might not correspond to exact flap deflection angles, for the purpose of this Task they were assumed to match.

Table 2. 737-800 Approach Profile From AEDT

Flap ID	Thrust Level	Altitude AFE (ft)	Calibrated Airspeed (kt)
A_00	Unknown Thrust	6000	248.93
A_00	Idle Approach	3000	249.5
A_01	Idle Approach	3000	187.18
A_05	Idle Approach	3000	174.66
A_15	Unknown Thrust	3000	151.41
A_30	Unknown Thrust	2817	139.11

The approach configurations were then used to create configuration-specific NPDs using the correction function applied to the AEDT default NPD for this aircraft class. ANOPP was also used to generate NPDs for each configuration in the profile so that the corrected AEDT NPD could be compared against the configuration-specific NPD created with ANOPP; thus, the correction function results could be compared against the ANOPP results to determine the accuracy of the correction function. A series of figures comparing the data were created for each configuration in the profile, as well as tables containing the error between the ANOPP and the corrected baseline NPD. For the sake of brevity, only two of the six cases will be described in this report; however, the procedure for all configurations was the same.

The first configuration consisted of gear up, flap deflection of 1°, and a velocity of 187 kts. The error between ANOPP and correction function data was calculated as the difference between the solid and dashed lines shown in Figures 12a and 12b where they overlapped. Table 3 shows the calculated error at each distance.



(a). Uncorrected NPD comparison

(b). Corrected NPD comparison

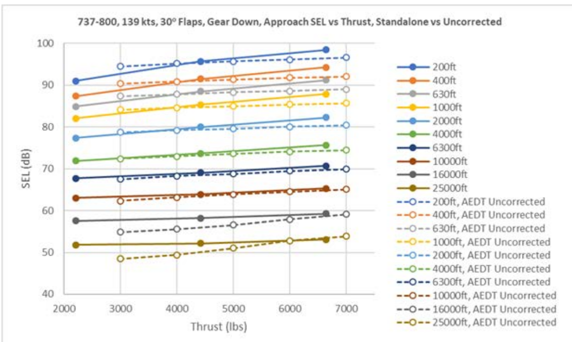
Figure 12. Correction function and ANOPP comparison for 187 kt, 1° FDA, gear-up configuration.

Table 3. Correction Function Error versus ANOPP for 187 kt, 1° FDA, Gear-Up Configuration

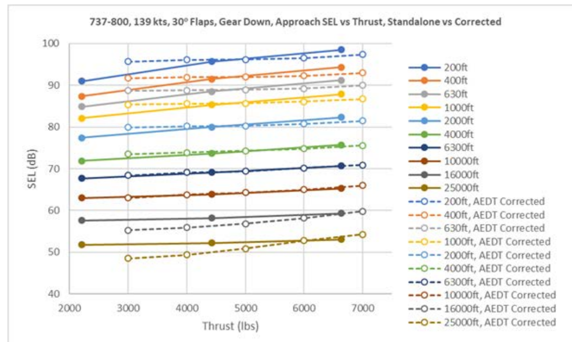
Distance	Uncorrected Error	Corrected Error
200 ft	1.02	-0.57
400 ft	1.17	-0.42
630 ft	1.09	-0.53
1000 ft	1.08	-0.61
2000 ft	1.12	-0.70
4000 ft	1.36	-0.71
6300 ft	0.43	-0.90
10000 ft	1.86	-0.78
16000 ft	1.02	-1.95
25000 ft	1.94	-1.45

As Table 3 shows, the correction function improved the absolute error between the AEDT NPD and the configuration-specific ANOPP NPD for all but two of the distance values. Moreover, there were only two distance values with SEL errors greater than one dB in magnitude. Figure 12 shows this graphically, where the solid lines indicate the ANOPP data and the dashed lines indicate the uncorrected (Figure 12a) and corrected AEDT default NPD (Figure 12b).

This process was repeated for a second case, involving a flight configuration of gear down, flap deflection angle of 30°, and velocity of 139 kts. As before, the uncorrected and corrected NPDs were compared against the ANOPP data in Figure 13, and the error between the ANOPP and uncorrected and corrected NPDs are shown in Table 4.



(a). Uncorrected NPD comparison



(b). Corrected NPD comparison

Figure 13. Correction function and ANOPP comparison for 139 kt, 30° FDA, gear-down configuration.

Table 4. Correction Function Error versus ANOPP for 139 kt, 30° FDA, Gear-Down Configuration

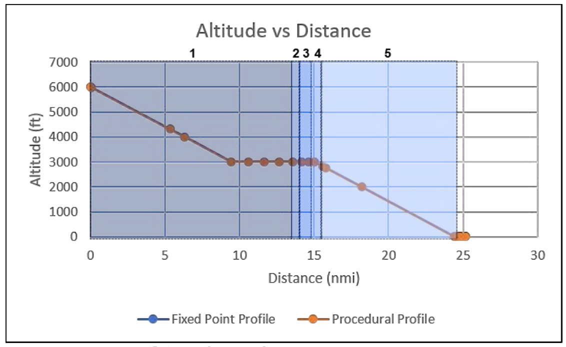
Distance	Uncorrected Error	Corrected Error
200 ft	-0.42	0.27
400 ft	-0.58	0.21
630 ft	-0.73	0.1
1000 ft	-0.80	0.08
2000 ft	-0.84	0.03
4000 ft	-0.64	0.19
6300 ft	-0.69	0.05
10000 ft	-0.51	0.05
16000 ft	-1.86	-1.55
25000 ft	-1.54	-1.54

As Table 4 shows, the correction function reduced the difference between the AEDT NPD and ANOPP data for all but one of the distances and resulted in only two SEL errors greater than 0.3 dB. This reduction of error is made more apparent in Figure 13, where the overlap between the NPD and ANOPP data increases upon application of the correction function.

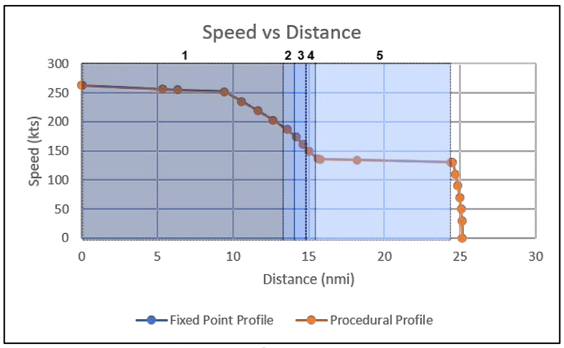
Next, a fixed-point profile was derived from the standard procedural profile for the 737-800 in AEDT. This profile is shown in Figure 14a. Figures 14b-14d compare the altitude, speed, and noise thrust against distance for the fixed-point and procedural profiles. As these figures show, both profiles are nearly identical such that only one is visible in each plot. The correction function was applied to the AEDT default NPD to create configuration-specific NPDs for all of the states in the profile, and the profile was simulated in AEDT using both the default and configuration-specific NPDs. Figure 15 shows the difference in the noise contours between the default and configuration-specific NPDs.

NPD	Speed	Flap Setting	Gear Setting
1	201 kts	0	Up
2	187 kts	1	Up
3	174 kts	5	Up
4	151 kts	15	Up
5	139 kts	30	Down

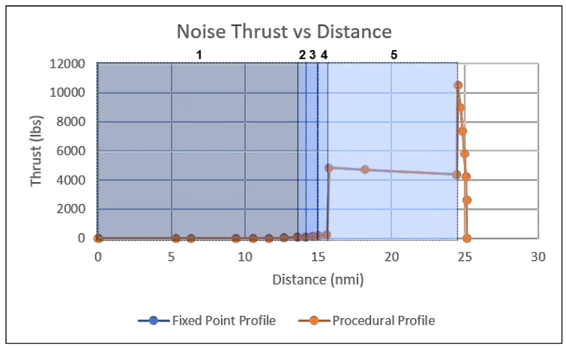
(a). Standard approach profile



(b). Altitude comparison



(c). Speed comparison



(d). Noise thrust comparison

Figure 14. Comparison of fixed-point and procedural profiles.

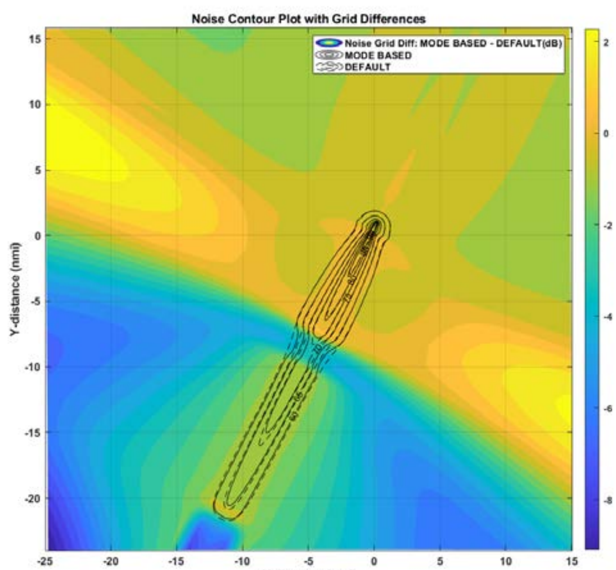


Figure 15. Comparison of uncorrected and corrected noise contours.

As Figure 15 shows, the largest difference between corrected and uncorrected NPDs occurs in segments/configurations 1–4, which is also seen in Figure 16. As the approach profile in Figure 14a shows, segments 1–4 reflect different flap settings with the gear retracted, while segment 5 reflects a 30° flap deflection and gear-down configuration. The contour plot reveals that the difference between the corrected and uncorrected noise contours is relatively small for the gear-down segment (shown in yellow and light green), while the difference is larger for the gear-up cases as shown via the dark blue levels in the contour plot.

The areas for several SEL values were calculated for both the uncorrected and corrected NPD simulation in AEDT, as shown in Table 5. This table shows that for SEL values below 75 dB, the predicted contour areas for the corrected NPD simulations were smaller than for the uncorrected NPD simulations. For SEL values at or above 75 dB, the predicted contour areas for the corrected NPD simulations were greater than for the uncorrected simulations.

Table 5. Contour Area Changes by SEL

Level (dB)	Contour Area (Default) (nm^2)	Contour Area (Mode based) (nm^2)	Δ (nm^2)
60	76.63	72.12	-4.51
65	48.02	44.62	-3.40
70	24.56	22.51	-2.05
75	10.00	10.10	+0.10
80	4.21	4.56	+0.35
85	1.21	1.33	+0.12
90	0.34	0.37	+0.03

Finally, the predicted difference between the SEL values for the uncorrected and corrected NPD AEDT simulations was calculated directly underneath the flight path, as shown in Figure 16. This figure shows that for the entire simulation, the predicted SEL difference never exceeded 3 dB in magnitude. It also highlights that the difference was at its greatest between 12 and 15 nmi along the flight path, corresponding to flight segments 2–4.

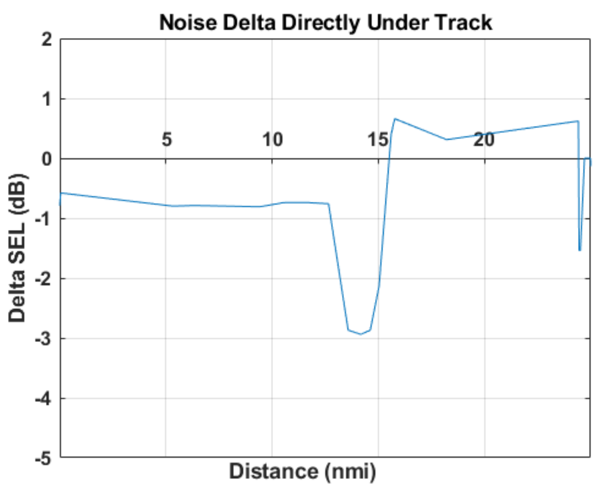


Figure 16. Plot of correction function values underneath track.

After developing the correction function for this aircraft class and testing it using a standard approach profile, it was then tested using FOQA data. Two representative tracks were selected from the FOQA dataset, consisting of approaches into SFO by a 737-800, a 737-900, and the corresponding matched noise monitor data. The objective of this was to see if the correction function improved the prediction in AEDT and was tested using the same method previously described—deriving a fixed-point profile from the track, correcting the default AEDT NPD for the configurations represented in the profile, and running the analysis using the mode-based NPD method to substitute configuration-specific NPDs.

First, the configurations represented in the FOQA tracks were plotted against the standard approach profile defined for these aircraft. This is shown below in Figures 17a-b, and indicates that although the true flight profile is similar to the standard profile as defined in AEDT, the configuration changes (in terms of flap and gear deployment) occur at higher speeds. Additionally, Figures 17c and 17d below show the tracks themselves modeled in AEDT.

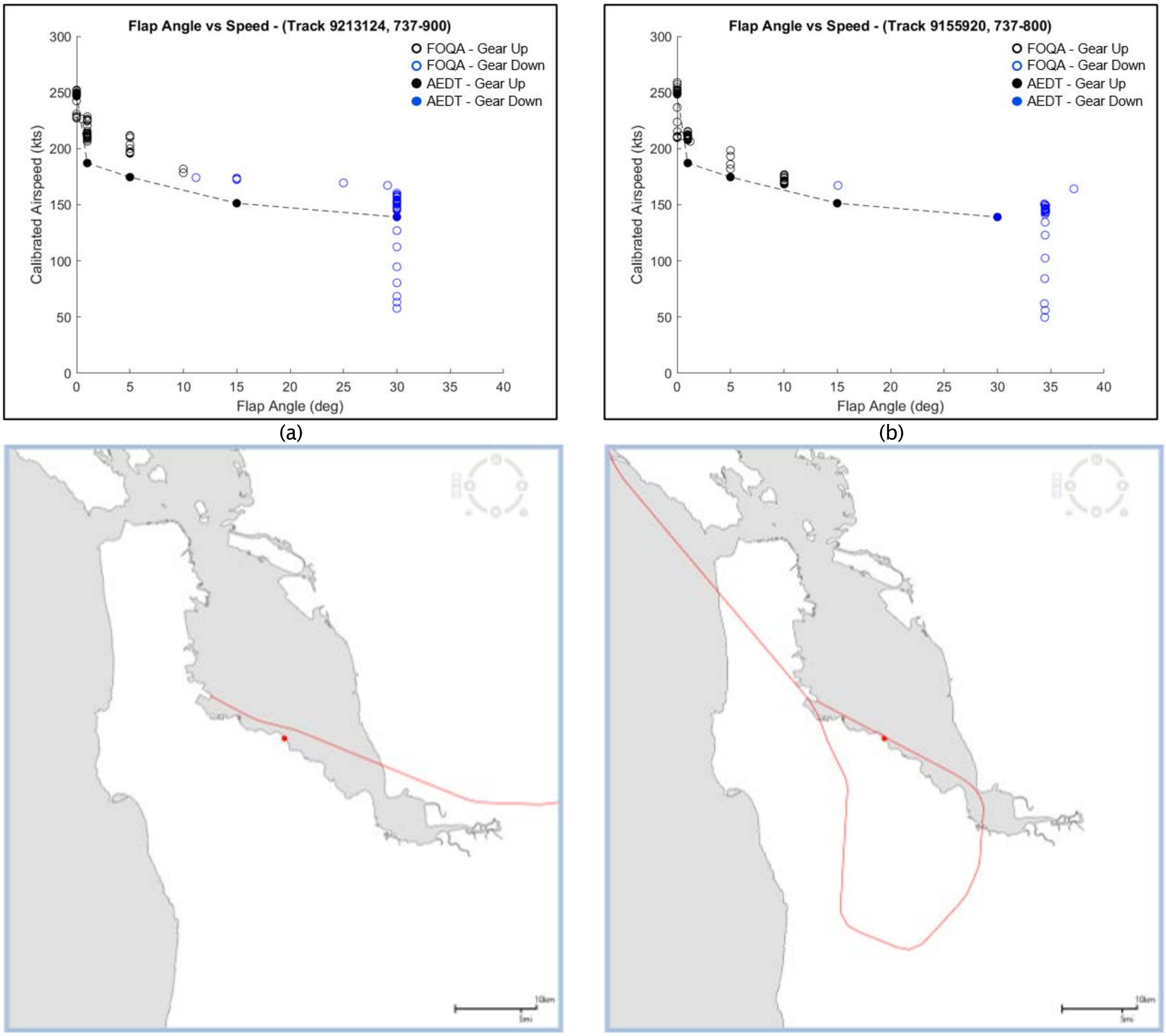


Figure 17. FOQA tracks and configurations.

For each of these tracks, configuration-specific NPDs were generated using the correction function for the FOQA and Standard profiles and the tracks were simulated with the corresponding noise monitor site modeled. A total of four test cases were run for each profile. The first two cases used the Standard approach profile, tested with both default NPDs and corrected

NPDs accounting for the configurations in the Standard approach profile. The second two cases used the FOQA profile, tested with both default NPDs and corrected NPDs accounting for the configurations in the FOQA approach profile. Tables 6 and 7 below contain the results from each of the test cases.

Table 6. Results for Track 9213124.

	SEL
Measured Value, Noise Monitor (Site 12)	76.0 dB
Standard Profile, Default NPD	72.15 dB
Standard Profile, Corrected NPDs	72.63 dB
FOQA Profile, Default NPD	70.92 dB
FOQA Profile, Corrected NPDs	72.79 dB

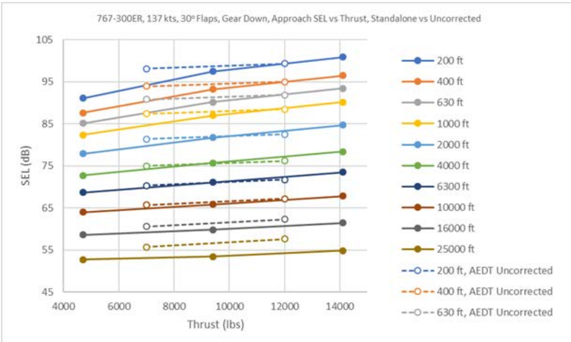
Table 7. Results for Track 9155920.

	SEL
Measured Value, Noise Monitor (Site 12)	81.6 dB
Standard Profile, Default NPD	81.44 dB
Standard Profile, Corrected NPDs	81.81 dB
FOQA Profile, Default NPD	80.25 dB
FOQA Profile, Corrected NPDs	81.37 dB

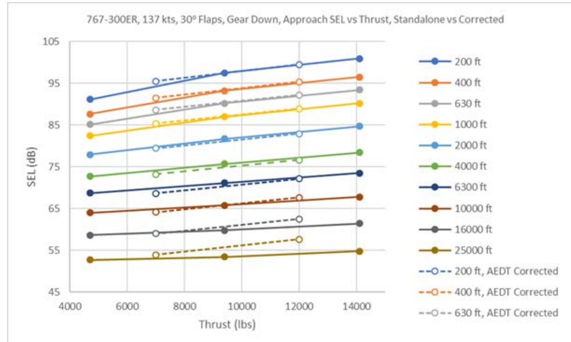
From these initial test cases, it can be seen that with the exception of the Standard profile for Track 9155920, the corrected NPDs improved the prediction at the noise monitor site. Additionally, the most pronounced change was observed between the FOQA profiles using the default and corrected NPDs. As a final check, the closest state to the noise monitor site was identified in order to see what was contributing the most at the nearest point. For the first instance (Track 9213124), the closest configuration in the FOQA profile was 154.25 knots, 30° flaps, and gear down. For the second instance (Track 9155920), the closest configuration in the FOQA profile was 167.25 knots, 15° flaps, and gear down. Given that the correction function predicts the difference from a baseline configuration of 160 knots, 15° flaps, and gear down, it makes sense that the changes observed were small for both tracks.

210pax Model Test

Once the model was completed and tested for the 150pax aircraft class, the entire process was repeated for the 210pax aircraft class using the 767-300ER as the baseline aircraft. Again, a correction function was developed using EDS, ANOPP, and JMP, and applied to the baseline NPD to test its accuracy. Figure 18 plots the default AEDT NPD for this aircraft against ANOPP for the same state, and Figure 18b plots the corrected AEDT NPD against the ANOPP results. These figures show that for each distance except for 2000, 4000, and 6300 ft, the correction function decreases the error between the NPD and the ANOPP prediction for the given configuration. The error between the uncorrected and corrected NPDs and the ANOPP results is shown in Table 8.



(a). Uncorrected NPD comparison



(b). Corrected NPD comparison

Figure 18. Correction function and ANOPP data comparison for 137 kt, 30° flap deflection, gear-down configuration.

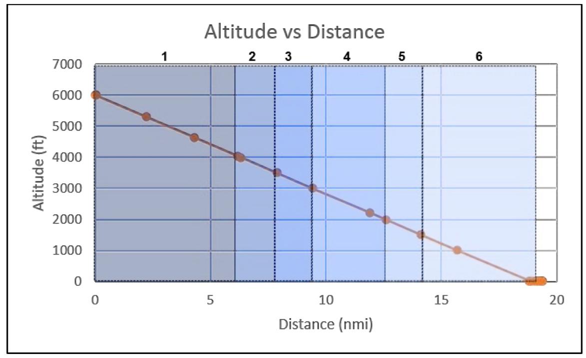
Table 8. Correction Function Error versus ANOPP for 137 kt, 30° Flap Deflection, Gear-Down Configuration

Distance	Uncorrected Error	Corrected Error
200 ft	1.51	0.31
400 ft	1.48	0.43
630 ft	1.33	0.38
1000 ft	1.06	0.21
2000 ft	0.29	-0.50
4000 ft	-0.11	-0.81
6300 ft	-0.14	-0.79
10000 ft	0.58	-0.01
16000 ft	1.56	0.86
25000 ft	3.13	2.23

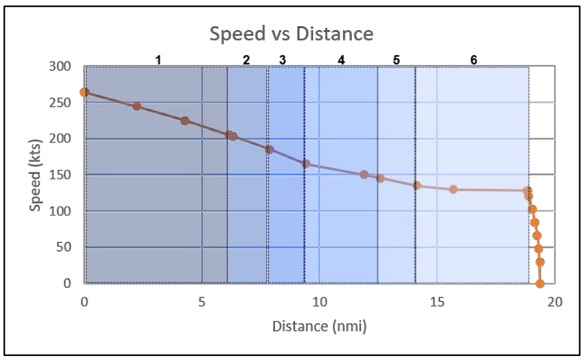
Next, a fixed-point profile was derived using the Standard approach profile in AEDT for the 767-300ER aircraft class, and the uncorrected and corrected NPDs were tested in AEDT. Figure 19 shows the fixed-point profile used for testing the 210pax model.

NPD	Speed	Flap Setting	Gear Setting
1	220 kts	0	Up
2	204 kts	0	Up
3	185 kts	0	Up
4	167 kts	5	Up
5	141 kts	25	Up
6	137 kts	30	Down

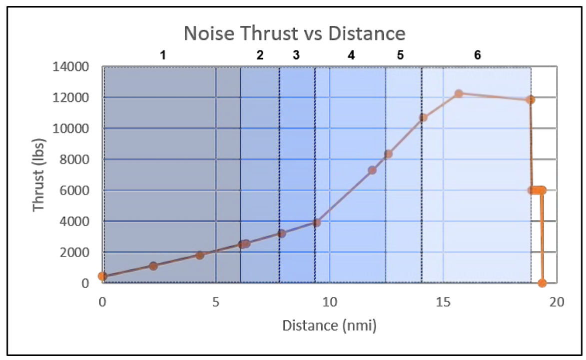
(a). ANOPP profile



(b). Altitude comparison



(c). Speed comparison



(d). Noise thrust comparison

Figure 19. Fixed-point profile used for testing.

As the profile shows, six different states made up the flight profile. Three configurations contained zero flap deflection at various speeds, one consisted of a flap deflection angle of 5° at a speed of 167 kts, another consisted of a flap deflection angle of 25° at a flight speed of 141 kts, and the final configuration consisted of a flap deflection angle of 30° and gear-down configuration.

With the profile identified, the default and corrected NPDs were used to simulate the approach and generate noise contours and grids for comparison. Figure 20 plots the difference between the uncorrected and corrected NPD simulation from AEDT.

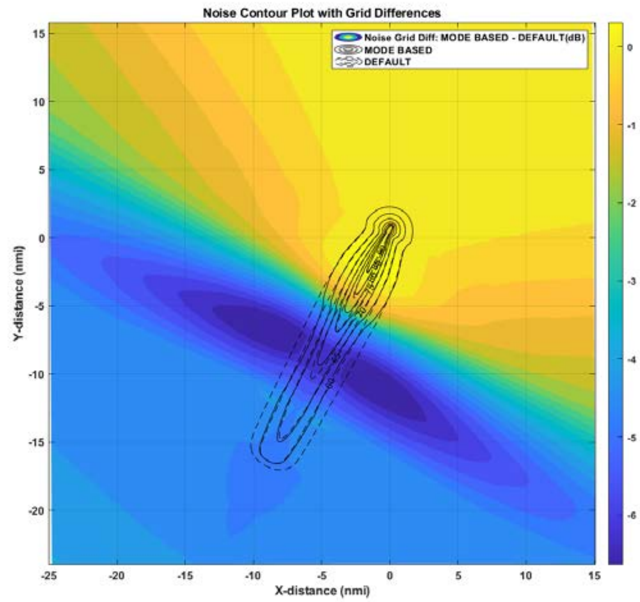


Figure 20. Noise contour plot of difference between uncorrected and corrected NPD.

As the contour plot shows, the largest difference between the uncorrected and corrected NPDs was located at the clean configuration states along the profile. As the flap deflection angle increased and the gear deployed, the difference in the uncorrected and corrected NPD decreased as shown by the lighter yellow contours near the origin of the contour plot. Once again, the contour areas were calculated for various SEL values, as shown in Table 9.

Table 9. Comparison of SEL Contour Areas

Level (dB)	Contour Area (Default) (nm^2)	Contour Area (Mode based) (nm^2)	Δ (nm^2)
60	85.30	65.62	-19.68
65	54.44	37.23	-17.21
70	29.91	18.06	-11.85
75	14.25	9.79	-4.46
80	6.31	5.39	-0.92
85	2.60	2.60	0.0
90	0.92	0.99	+0.07

This table shows that for SEL values at or below 80 dB, using the corrected NPDs resulted in decreased contour areas, while for SEL values above 80 dB the contour areas were slightly increased. For SEL values of 60, 65, and 70 dB, the decrease in contour area between the uncorrected and corrected NPDs was significant, ranging in magnitude from 11.85 to 19.68 nm^2. For SEL values of 85 and 90 dB, the change in contour area was less than 0.1 nm^2. Figure 21 was also created from the AEDT simulation results to show how the correction function resulted in different SEL values across the fixed-point profile.

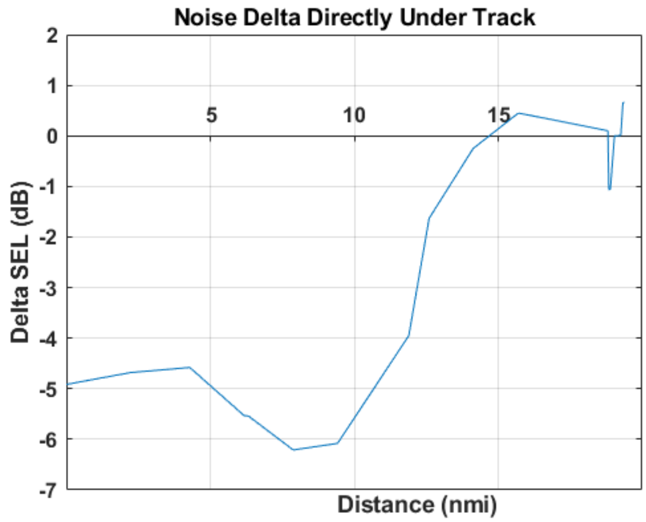


Figure 21. Difference in SEL values directly under flight path.

This plot shows that the greatest difference in SEL values underneath the flight path occurred between 7 and 10 nmi along the flight path. As Figure 19 shows, this corresponds to flight segments 2–4. This is sensible, given that the greatest difference in SEL values from the uncorrected and corrected AEDT simulations occurred when the aircraft was in a clean configuration at the slowest of the modeled speeds for that state, which the aircraft was in for segments 2 and 3.

Although the next step would be to test using FOQA tracks and associated noise measurements, at the time of this report the team did not have any matched tracks and noise data for aircraft in the 210-pax class. As such, although interim tests could be performed using aircraft outside of this class, additional data should be available soon and the corresponding evaluations will be able to be performed then.

Milestone

Develop correction functions across vehicle classes.

Major Accomplishments

Developed correction functions across vehicle classes and compared to real-world noise monitoring data.

Plans for Next Period

With the 150pax and 210pax class models complete, new models will be created for the 50pax and 300pax classes, following the same approach as described previously. Once the models are completed, they will be compared against “truth data” in the form of real-world noise observations for aircraft of the same class.

Other Work Supporting Tasks (AEDT Tester Development)

Georgia Institute of Technology

Objective(s)

Georgia Tech has developed a wrapper (AEDT Tester) around the AEDT source code that allows for the automation of reading aircraft definition and flight procedures input files with less user interaction and higher efficiency. AEDT Tester was initially developed to work with AEDT 2e. The first objective of this task is to synchronize AEDT Tester with the latest AEDT release – AEDT 3c.

Modifications were made to AEDT source code to incorporate NPD + Configuration (NPD+C), which accounts for varying aircraft speed and configuration parameters such as flap/gear/speed to achieve more accurate noise evaluation; however, the code was lost. The second objective of this task is to re-implement NPD+C.

Research Approach

AEDT Tester Synchronization

Figure 22 shows the general workflow of AEDT Tester. In order to synchronize AEDT Tester with the latest AEDT release – AEDT 3c. The team has rebuilt AEDT Tester by modifying its code to accommodate the new AEDT's interface.

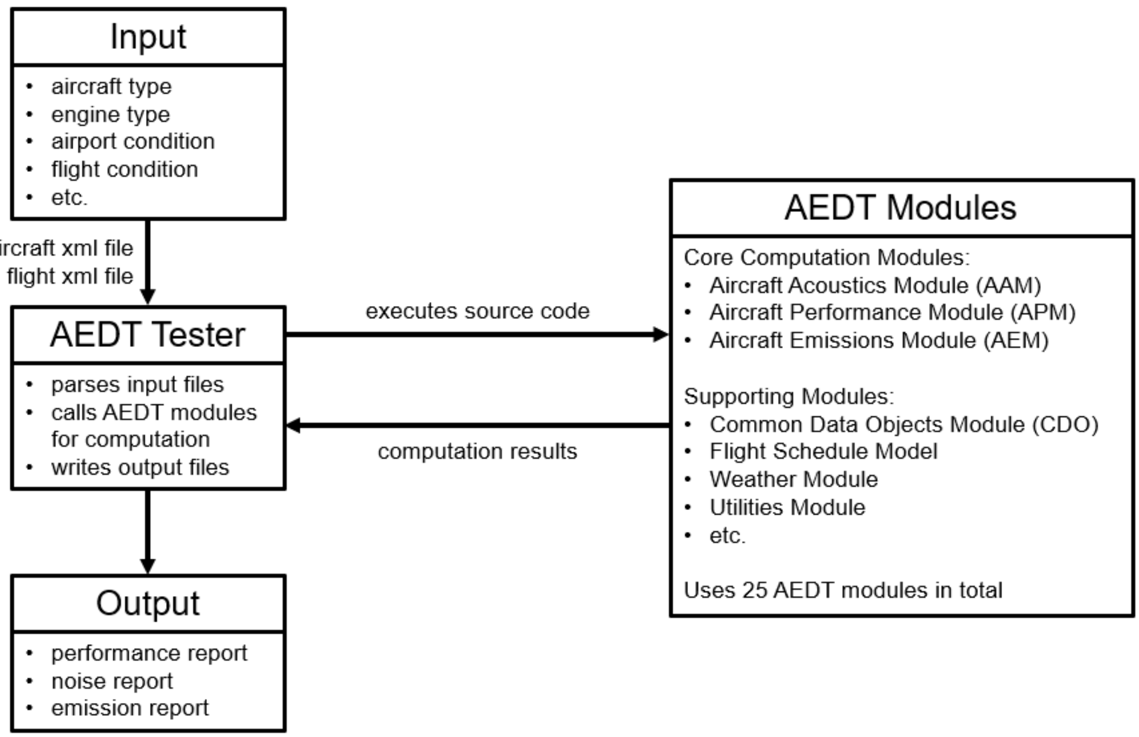


Figure 22. Workflow of AEDT Tester.

The new AEDT Tester achieved all expected functionalities, including parsing input aircraft and flight files, calling AEDT modules for computation, and writing output files. The team then performed a quantitative validation by running an identical case in AEDT Tester and AEDT 3c and comparing the results. The aircraft used was B737-800, the reference airport was SFO, and comparisons were done for both departure and arrival operations. Theoretically, the computational results of AEDT Tester, including performance, noise, and emission, should exactly match the results from AEDT 3c. The results showed that discrepancies, although not large, do exist between the two program's results. The team is investigating the reasons that have caused the differences.

NPD+C Implementation

The Georgia Tech team has made modifications to both AEDT Tester and AEDT source code to incorporate NPD+C in noise computation. The modifications required an involvement within AEDT Tester itself and 3 main AEDT code modules which are: Aircraft Acoustics Module (AAM), the Aircraft Performance Module (APM) and the Common Data Objects (CDO) module. Here we provide a conceptual description to summarize the modifications in code. Detailed modifications are specified in Table 10.

AEDT Tester: The modifications in AEDT Tester focused on parsing the expanded input aircraft .xml file, which included a superset of NPDs. First, the input schema .xsd file was modified to accommodate multiple NPDs in the input file. Then, the code segments, such as NpdCurveLongRecord_NPDC() and GetNoisePowerDistanceCurves_NPDC(), for parsing the input .xml file and constructing NPD+C curves were altered to read the multiple noise power distance curves and create NPD+C curves within the program. Functions for output purposes were updated to include flap and gear information for each flight segment.

CDO: The modifications in the CDO module were parallel to the changes in AEDT Tester's. Two new classes, NpdDataAircraft_NPDC and NpdCurveLongRecord_NPDC, were made to create new containers to store the information of the expanded NPDs, namely flap id, gear setting, and speeding setting. TrajectorySegment class was also adjusted to include flap id in flight segments.

APM: Much code was altered in the APM module to allow for the passing of aircraft configuration information obtained from the input .xml file all the way to flight segment containers, which were used for noise computation.

AAM: The majority of modifications in this task occurred in the AAM module for implementing the new noise interpolation method that works with NPD supersets. NpdData.cs class was modified to store the NPD superset in high dimensional matrices. MainContainer.cs was the key class that went through the heaviest modifications as it is where the noise interpolation takes place. NoiseInterpolation_NPDC() was altered to perform the 4-d interpolation, which took advantage of the original 2-d interpolation logic that AEDT originally had. The new noise interpolation did not make any internal changes to the existing one, but rather used the 2-d interpolation's results as the input for the high dimensional interpolation. To facilitate the new interpolation logic, a couple of other functions and interfaces were updated in MainContainer.cs

.

Table 10. NPD+C Implementation Specifics.

AEDT SOLUTION MODIFICATIONS FOR NPD+C IMPLEMENTATION					
Project	Class / File	Method / Class	Line(s)	Description	Related Mods
AAM (Aircraft Acoustic Module)	CDOAAMInterface.cs	CopyCDONoiseParameterstoNPDObj()	1839-1841	Assign values for the aircraft configuration labels in NpdDataAircraft object	
			1947-1962	Assign number of different curves in NpdInfo	NpdData.cs
		FindNPDIndices()	2420-2440	Find the first occurance of departure curve in the npd curve list	
		CopyCDOTrajectorySegmenttoFlightPathSegment()	1555-1564	Pass flap_id and height from trajecotry segment to flight path segment airplane	
	FlightPathSegment.cs	FlightPathSegmentAirplane : FligthPathSegmentBase	171-174, 210-217	Include flap_id in the class	
	MainContainer.cs	SegmentContainer	4011-4012	Include gear setting in SegmentContainer class to be used for noise interpolation	
			3961-3965	Flap-related member variables in Segment Container class for interpolation	
			272-273	While initialization, pass flap_id from FlightPathSegmentAirplane to SegmentContainer and set the actual flap value	
			275-282	Initialize gear setting for segment container based on aircraft height	
			3985-3986, 274	Add height as a member variable and pass height when convert flight path segment into segment container	
		ParseFlapId()	381-394	Utility function to parse flap_id into float value	
		AircraftNoiseCurveStorage()	474-858	Fill values from npd curves into the noise matrix	
		Exposure()	1838-1842	Call new interpolation function to do noise computation	
		NoiseInterpolation_NPDC()	2799-2862	New interpolation algorithm based on AEDT original algorithm to do 4-d interpolation	
		FindFlapSpeedGearIndices()	3160-3195	Function to look for the two labels that box the desired flap/speed/gear values of the data point	
		NoiseInterpolation_ThrDist()	2864-3159	Modified AEDT's original algorithm's interface to perform interpolation on thrust and distance with NPD+C curves	
	NpdData.cs	NpdInfo	12-107	Include numbers of thrust, flap, speed, and gear settings into the NpdInfo class	
		NpdDataAircraft : NpdBase	218-271	Include aircraft configuration settings into the class	
		NOISE_MATRIX_TYPE	379	Change the noise matrix dimension for it to be able to contain configuration data	

			399-409	Initialize the size of the noise matrix	
AEDTTester	AircraftXmlReader.cs	AircraftXmlReader	50	Modified AEDT's reader schema to incorporate the new vehicle XML input containing the information of the superset of NPDs.	EDS2AEDTFLEET_dummy.xsd
		GetNoiseParameters()	1887	Calling new method GetNoisePowerDistanceCurves_NPDC() to get NPD+C curves from xml elements.	
		NpdCurveLongRecord_NPDC()	2297-2416	Reading from xml element to construct the NPD+C records, which will later be used to create NPD+C curves	NpdCurveLongRecord_NPDC.cs
		GetNoisePowerDistanceCurves_NPDC()	2054-2120	Calls NpdCurveLongRecord_NPDC() funtion to create NPD+C curves.	NpdDataAircraft_NPDC.cs
		GetEngineEmissions()	664-685	Allow null values for some emission related data in the input	
		GetNoiseParameters()	1881-1918	Parsing the input data with "EDS_aircraft" format	
		GetNoisePowerDistanceCurves_NPDC_EDS()	2181-2185	Parse aircraft configuration data	
	ResultCSVWriter.cs	SavePerformanceAndEmission()	840-1131	Include flap and gear information	
		SavePerformanceAndNoise()	1194-1349	Include flap and gear information	
(APM) Aircraft Performance Module	FlightPath.cs	add_alt_interval_points_terminal()	433	Pass flap_id when interpolating new path points	
	AirplaneProfile.cs	AssignContextToStep()	365-367	Pass flap_id when going from profile steps to the original path points	
	TerminalOp.cs	CreateAirplaneTerminalFlightPathSegments()	432-433	Pass on flap_id when to flight path segment	FlightPathSegment.cs
	FlightPathSegment.cs	FlightPathSegmentAirplane	All	Add flap_id and height as member variables to the class	
	EventModeler.cs	PopulateCDOPerformanceEventResultFromFlightPath()	1002	Pass gear to trajectory segment	
			1091	Pass gear to the last trajectory segment	
			985	Pass flap_id to trajectory segment	TrajectorySegment.cs
			1076	Pass flap_id to the last trajectory segment	
(CDO) Common Data Objects	NpdDataAircraft_NPDC.cs	NpdDataAircraft_NPDC	All	A sibling class of the original NpdDataAircraft class in AEDT, extra fields to include flap, gear, and speed settings so it becomes a superset of the original class	
	NpdCurveLongRecord_NPDC.cs	NpdCurveLongRecord_NPDC	All	A sibling class of the original NpdCurveLongRecord class in AEDT, extra fields to include flap, gear, and speed settings	
	TrajectorySegment.cs	TrajectorySegment	50-145, 448-453	Include flap_id in the class fields and created a new constructor	
	ITrajectorySegment.cs	ITrajectorySegment	120-124	Include flap_id in the interface	

The validation was done with respect to the NPD+C implementation. A test case was performed using B737-800 for an arrival flight at San Diego International Airport (SAN) and an NPD+C superset consisting of 12 identical baseline NPD curves was used as NPD+C noise curves. Since in this case the NPD+C algorithm essentially used the same baseline curve as the NPD algorithm, the algorithms had to produce identical noise results. Figure 23 shows the comparison of noise contours of the experiment, and a good match between the two result sets can be observed. The validation test has succeeded.

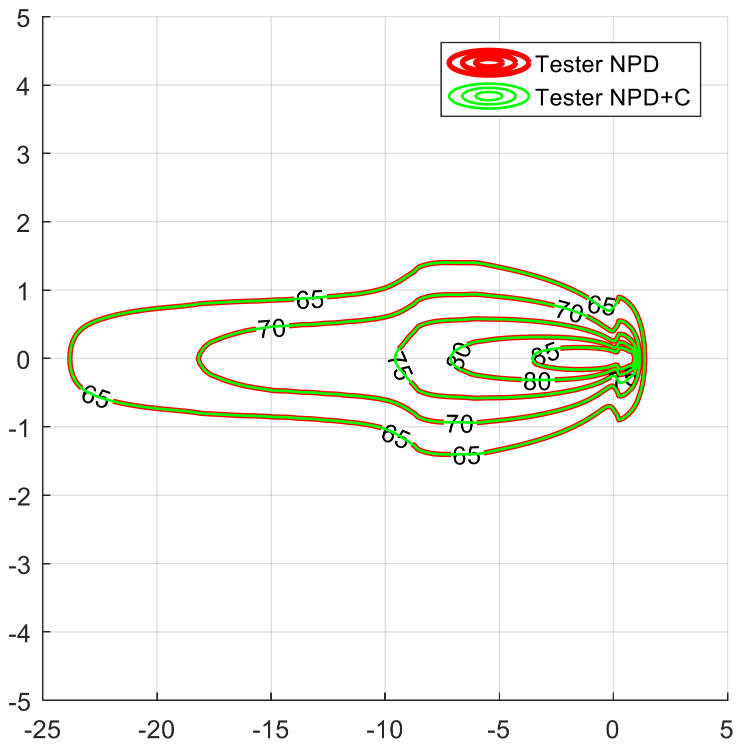


Figure 23. Noise contour comparison of NPD and NPD+C algorithms.

Milestone
N/A

Major Accomplishments
Recompiled the AEDT Tester.

Plans for Next Period
Continue debugging in the AEDT Tester to investigate the causes of the discrepancies between AEDT 3c and the AEDT Tester's results, including performance, noise, and emissions.

Utilize AEDT Tester to perform experiments on FOQA flights with NPD and NPD+C and compare the noise results obtained by the two approaches against truth data to determine the effectiveness of incorporating NPD+C for noise evaluation.

Publications
N/A

Outreach Efforts
N/A

Awards
N/A

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