Project 036 Parametric Uncertainty Assessment for Aviation Environmental Design Tool (AEDT)

Georgia Institute of Technology

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- Task(s):
    1. AEDT 2b Uncertainty Quantification Closeout Study
    2. Validation and Verification of BADA4 Implementation
    3. Capability Demonstration and Validation of AEDT 2c and 2d Functionality

Project Funding Level

According to the original project plan, the funding from the FAA is $175,000 for 12 months. The Georgia Institute of Technology has agreed to a total of $175,000 in matching funds. The project was augmented for the period for 12/1/2016 to 3/31/2017 to add additional tasks. The augmented funding from the FAA is $80,000 for 4 months. The Georgia Institute of Technology has agreed to additional $80,000 in matching funds. The next augmentation was for $300,000 for the period of performance of 4/1/2017 to 8/31/2018. The Georgia Institute of Technology has agreed to additional $300,000 in matching funds.

Investigation Team

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Project Overview

The Federal Aviation Administration's Office of Environment and Energy (FAA/AEE) has developed a comprehensive suite of software tools that allow for a thorough assessment of the environmental effects of aviation, in particular the ability to assess the interdependencies between aviation-related noise and emissions, performance, and cost. At the heart of this tool suite is the high fidelity Aviation Environmental Design Tool (AEDT). AEDT is a software system that models aircraft performance in space and time to estimate fuel consumption, emissions, noise, and air quality consequences. This software has been developed by the FAA Office of Environment and Energy for public release. It is the next generation FAA environmental consequence tool. AEDT satisfies the need to consider the interdependencies between aircraft-related fuel consumption, emissions, and noise. AEDT 2 has been released in four phases. The first version, AEDT 2a, was released in March 2012 [1, 2]. The second version of AEDT 2b was released in May 2015 [3], the third version of AEDT 2c was released in September 2016, and the fourth version of AEDT 2d was released in September 2017. A new series AEDT 3 will be released which have major updates including Base of Aircraft Data 4 (BADA4) performance model for fuel consumption, emissions and noise, and implementation of ASCENT Project 45 findings.

This uncertainty quantification comprehensively assesses the accuracy, functionality, and capabilities of AEDT during the development process. The major purposes of this effort are to:

- Contribute to the external understanding of AEDT
- Build confidence in AEDT’s capability and fidelity (ability to represent reality)
- Help users of AEDT to understand the sensitivities of output response to the variation of input parameters/assumptions
- Identify gaps in functionality
- Identify high-priority areas for further research and development

The uncertainty quantification consists of verification and validation, capability demonstrations, and parametric uncertainty/sensitivity analysis.

Task #1: AEDT 2b Uncertainty Quantification Closeout Study

Georgia Institute of Technology

Objective(s)

Aviation Environmental Design Tool (AEDT) is a software system that models aircraft performance in space and time to estimate fuel consumption, emissions, noise, and air quality impacts. This software, developed by the FAA Office of Environment and Energy (AEE), is the next generation FAA environmental consequence tool. In order to ensure the accuracy, functionality, and capabilities of AEDT 2b during the development process, Uncertainty Quantification (UQ) analyses were conducted to assess AEDT 2b’s capability and fidelity [3]. Additional objectives of the UQ analysis also include contributing to the external understanding of AEDT 2b, helping users of AEDT 2b to understand sensitivities of output response to variation in input parameters/assumptions, identifying gaps in functionality, and identifying high-priority areas for further research and development [4, 5].

Since AEDT 2b replaces legacy software tools (e.g., Integrated Noise Model (INM), Emissions and Dispersion Modeling System (EDMS), and AEDT 2a), the UQ analyses were designed as a verification/validation of the capability of AEDT 2b. For noise, fuel consumption and emissions modeling, UQ analyses were conducted by evaluating AEDT 2b against INM, EDMS and other legacy tools. The comparison shows that there are relatively large differences in noise, fuel consumption, emission inventory and emission dispersion between AEDT and the legacy tools. Thus, a further investigation was performed to assess and understand the causes that lead to the differences. This section presents the studies for investigating a number of factors that may have impacts on the noise and emissions results produced by AEDT and the legacy tools. The findings and recommendations about the uncertainty quantification analysis for AEDT on noise and emissions were also presented and discussed.

Research Approach

To understand and validate the capability of AEDT 2b, further analysis is conducted to investigate the causes that lead to the differences in noise, fuel burn, emission inventory and emission dispersion between AEDT 2b and the legacy codes. For emissions analysis, since the differences in emission inventory mainly result from the aircraft and other sources like GSE, APU and stationary sources’ contributions to the differences can be neglected, the investigation is focused on the differences produced only by aircraft.

The investigations of the difference between AEDT and the legacy tools focus on evaluating the assumptions, methods, and implementation for noise and emissions calculations. Thus, the technical manuals of AEDT and legacy tools were reviewed to understand the assumptions and methods used, and the factors that have impact on the noise and emissions calculation were identified. Additional studies were designed and performed to further validate the metric results, and findings and recommendations were discussed.

Investigation of the Differences in Emissions Inventory and Dispersion between AEDT and EDMS

To evaluate AEDT 2b's capability in modeling fuel consumption, emission inventory and emission dispersion, a NEPA/CAA analysis was used to provide a verification and validation of AEDT 2b functionality and a comparison to EDMS. This analysis utilized a single airport study for testing the functionality and comparing the results to EDMS [3]. The comparison results show that for emission inventory analysis of the aircraft sources, the difference in fuel consumption, CO2, H2O, and SOx is about 14~15% between AEDT 2b and EDMS. The differences in HC, TOC, VOC, and NMHC aircraft emissions are about -3%, and the difference in NOx is about 15%. PM features the largest difference between AEDT 2b and EDMS, ranging from -17% to -26%. In addition, for air quality analysis, the difference in pollutant concentration can be as large as 76% (e.g. CO 1 HR concentration) between AEDT and EDMS. Thus, the goal of this task was to investigate the causes that lead to the difference between AEDT and EDMS by comparing factors

- Weather
- Engine Emission Databank (EDB) coefficients
- ANP coefficients, flight procedure and trajectory
- Taxi time
- Aircraft and operation type
- Operation modes
- Fuel burn and emissions calculation methods
- Flight track
- Spatial assignment of emissions for dispersion modeling
- Aircraft operation

Investigation for Fuel Consumption and Emission Inventory Modeling

The causes that led to the differences in fuel consumption and emission inventory between AEDT and EDMS are investigated [3, 4, 6, 7]. The factors that were investigated include weather, engine emission databank coefficients, ANP coefficients, flight procedure and trajectory, taxi time, aircraft and operation type, operation modes, and fuel burn and emissions calculation methods.

Weather

This analysis was performed to make sure both AEDT and EDMS use the same weather profile when calculating fuel burn and emissions since weather can have a significant impact on the results. It was found that AEDT uses different temperature, pressure, sea level pressure, relative humidity and wind speed values than EDMS. To enable an apples-to-apples comparison, the weather in AEDT was edited to match the weather in EDMS. AEDT was then re-run and the results show that for aircraft sources, the difference in fuel burn and all emissions except for NOx improved slightly.

Engine Emission Databank (EDB) Coefficients

Both AEDT and EDMS use Emission Indices (EIs) to calculate emission inventory for aircraft and non-aircraft sources. EI is the emissions produced per unit fuel consumed which are available in the ICAO engine emission certification databank (EDB). The EDB is a living DB and the data is continuously updated as new data becomes available. EIs have direct impact on the emission inventory results and it is necessary to compare the EDB coefficients (EIs) between AEDT and EDMS. For each engine, the AEDT Fleet database contains the EIs and fuel flow values corresponding to the standard landing-and-takeoff (LTO) cycle modes, including takeoff, climbout, approach, and idle. The EDB coefficients of AEDT and EDMS were compared. The comparison showed that, for most of the engines the EI values were the same. For some of the engines, however, AEDT and EDMS use very different EIs. This indicates that the difference in EIs contribute to the difference in emissions results produced by AEDT and EDMS.

ANP Coefficients, Flight Profile and Trajectory

Additional AEDT and EDMS assumptions and inputs were also compared, including ANP coefficients and flight profile. Both AEDT and EDMS use the STANDARD flight departure procedure and same ANP coefficients for all the aircraft. The flight trajectories generated by AEDT and EDMS were compared to investigate possible differences in the APM used by AEDT and EDMS. It should be noted that EDMS does not store trajectory information, but EDMS uses the same APM module as INM. Therefore, the trajectory was actually generated by INM when conducting the comparison. The comparison shows that the trajectories were almost identical except that AEDT calculates more segments. This implies that there is no major difference in the APM between AEDT and EDMS. Thus, ANP coefficients, flight profile and APM did not contribute to the difference in fuel burn and emissions for AEDT and EDMS.

Taxi Time

In the LTO operations, taxi in/out segments are important since these segments contribute approximately 30% of the terminal area fuel consumption. The fuel burn for a taxi segment is calculated by multiplying the taxi time by the fuel flow. In order to compare the fuel burn and emission between AEDT and EDMS, one must make sure both tools use the same taxi time. To investigate the impact of taxi time, one small study was built consisting of six aircraft selected from the study and run through AEDT and EDMS respectively. Identical taxi times were assigned to the operations of the six aircraft, with taxi out time as 19 minutes and taxi in time as 7 minutes. The results showed that even with the same taxi time, for most of the aircraft, the fuel burn and emission results produced by AEDT and EDMS still have large difference which makes it necessary to look into other factors which will be discussed in the following sections.

Aircraft and Operation Type

Another observation that can be drawn from the analysis conducted using the study presented in previous section is that Boeing aircraft showed better agreement in fuel burn and emissions than Airbus aircraft. In addition, fuel burn and emissions calculated for departure operations showed much better agreement than those calculated for arrival operations by AEDT and EDMS. It is shown that the difference in fuel burn and NOx between AEDT and EDMS is very small for Boeing aircraft, especially, for the Boeing 737-300 (2%, 1% for fuel burn and NOx, respectively).

Operation Mode

The aircraft level study discussed in previous section shows that the Airbus 320-200 featured the biggest difference in fuel burn and NOx among the six aircraft. In this analysis a further investigation was conducted to better understand the causes. A single A320-200 flight study was built, consisting of a departure and arrival operation. The study was run in AEDT and EDMS, and the fuel burn results were compared by mode. It was found that AEDT produced much more fuel burn for climb out and approach modes, while EDMS produced more fuel burn for taxi modes. In order to verify this finding, another single flight study was built using Boeing 737-700, and the fuel burn results was compared by mode. The comparison also indicate the same trend as found in the A320-200 single flight study.

Fuel Burn and Emissions Calculation Methods

Based on the analysis in previous section, it can be seen that AEDT and EDMS produce very different fuel burn for each LTO mode. Further investigation was done by reviewing the AEDT and EDMS manuals to understand the methods used for calculating fuel burn and emissions. The methods are summarized in Table 1. It can be seen that except fuel burn, both AEDT and EDMS use the same methods to calculate the emissions (for PM, they both used FOA 3a). AEDT can use three different models for fuel consumption, and EDMS only uses Boeing Fuel Flow Method 2 (BFFM2). Based on the AEDT technical manual, for terminal area modeling, AEDT uses:

- Senzig-Fleming-Iovinelli (SFI) fuel burn model when the proper coefficients are available;
- BADA fuel burn model when coefficients for the SFI fuel burn model are not available;
- BFFM2 when other sources for fuel consumption data are not available or when thrust is not a parameter in the aircraft’s performance profile.

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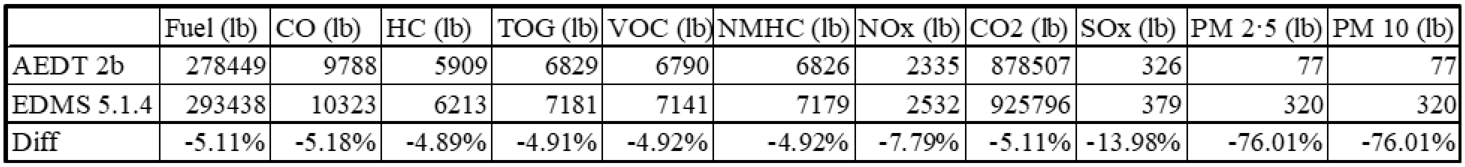
Table 1: Fuel Burn and Emission Methods Used by AEDT and EDMS

Fuel Burn/Emissions	AEDT	EDMS
Fuel Burn	Senzig-Fleming-Iovinelli (SFI) BADA fuel burn model BFFM2	BFFM2
NOx, HC, and CO	BFFM2	BFFM2
PM	FOA 3.0	FOA 3.0 - Non-US airport
	FOA 3a	FOA 3a - US airport
SOx, CO2	Fuel composition-based factors	Fuel composition-based factors
NMHC, VOC, TOG	Derivative factors	Derivative factors

The mathematical equations of these three methods can be found in the AEDT technical manual [3]. For this study. SFI coefficients were available for all the aircraft, therefore AEDT used the SFI method to calculate the fuel consumption, while EDMS used BFFM2 to calculate the fuel consumption. The use of different fuel consumption models is the main cause that led to the difference in fuel burn between AEDT and EDMS, which sequentially caused the difference in emissions calculated via EIs operating on the per segment fuel consumption.

In AEDT 2b, the thrust setting type, rather than pounds of thrust, is recognized as 'other', and the aircraft that use such thrust setting in AEDT are denoted as TTO aircraft. To further verify this conclusion, a TTO aircraft emission analysis study was conducted. This is a single airport (DULLES airport) study consisting of 119 TTO aircraft, mainly military aircraft. Originally, the fuel burn difference between AEDT and EDMS was found to be about -51%. After the weather, emission indices, ANP coefficients, flight procedure, flight trajectory, and taxi time were matched between the AEDT and EDMS studies, the fuel difference reduced to -5%, as shown in Table 2. Since the study is for TTO aircraft, AEDT uses the same fuel consumption model as EDMS uses – BFFM2. This implies that with all the assumptions and inputs matched, AEDT and EDMS show good agreement on fuel burn and emissions result if they use the same fuel burn methods. It can be seen from Table 2 that the difference in PM results are still big, which is mainly due to that AEDT 2b used FOA3.0 method while EDMS used FOA3.0a method for calculating PM, as indicated in Table 1.

Table 2: Fuel Burn and Emission Comparison with Same Fuel Consumption Method



	Fuel (lb)	CO (lb)	HC (lb)	TOG (lb)	VOC (lb)	NMHC (lb)	NOx (lb)	CO2 (lb)	SOx (lb)	PM 2·5 (lb)	PM 10 (lb)
AEDT 2b	278449	9788	5909	6829	6790	6826	2335	878507	326	77	77
EDMS 5.1.4	293438	10323	6213	7181	7141	7179	2532	925796	379	320	320
Diff	-5.11%	-5.18%	-4.89%	-4.91%	-4.92%	-4.92%	-7.79%	-5.11%	-13.98%	-76.01%	-76.01%

Investigation for Air Quality Modeling
In this section, the causes that led to the differences in emission dispersion between AEDT and EDMS will be investigated. The factors that were investigated include flight tracks, AREA source, and aircraft operations.

Flight Tracks
Different flight tracks can have significant impact on the hourly emission rate and how the emissions are allocated spatially and temporally. Based on the EDMS technical manual, the aircraft flies straight-in and straight-out. Upon investigation of the flight tracks, it was determined that AEDT also uses straight-in/straight-out tracks for the PVD airport in this study. Thus, flight track definition does not contribute to the observed differences in emission concentrations between AEDT and EDMS in this case.

Spatial assignment of emissions

American Meteorological Society (AMS)/United States Environmental Protection Agency (EPA) Regulatory Model (AERMOD) is the module integrated in AEDT that handles the emission dispersion analysis. One of the basic inputs to AERMOD is the source information, such as the source location, size, orientation, etc. The emissions from the AERMOD sources are assigned spatially and temporally, and the respective hourly emissions rates are input to AERMOD for emissions dispersion calculations. Each aircraft operation is associated with respective aircraft movements and consists of a set of the flight segments. The EDMS distributes a flight segment's emissions between one or more rectangular AERMOD area sources while AEDT assigns them typically to square shaped sources. Since the difference in emission dispersion is mainly from aircraft operation, the investigation shifted focus to the spatial assignment of emissions.

After comparing the emissions source assignment data between AEDT and EDMS, it was further found that the area sources are constructed differently in these two tools. In AEDT, the size of ground source and airborne source are defined as 20(m)x20(m) and 200(m)x200(m) respectively, and the orientation angle for these sources are 0 (i.e. the sources align with the X (east) and Y (north) directions). On the other hand, in EDMS the size and orientation of the ground source and airborne source depend on the runways.

The differences in emissions source assignments in AEDT and EDMS lead to the different emission allocation, which is a major contributor to the differences in emission dispersion. Figure 1 shows an example of concentration comparison between AEDT and EDMS at each receptor location. It is the 2nd highest 1-HR average concentration for CO from all sources. It can be seen that the difference in area source definition between AEDT and EDMS has a big impact on the concentration value of the receptors.

In addition, the differences in emissions resulting from the differences in emissions methods, as shown in Table 1, also contribute to these differences in modeled concentrations. Especially the fuel consumption models are different between AEDT and EDMS, as discussed in the Fuel Burn and Emissions Calculation Methods section, and consequently this will contribute to the differences in emissions and emission concentration results.

Aircraft Operation Schedule

The aircraft operation schedule has a big impact on the emission dispersion as well. In this study, both AEDT and EDMS use a fixed random seed value to develop the pseudo-schedule based on the predefined operation profiles. Because of the difference in how flights are handled computationally, AEDT 2b and EDMS do not generate the same exact pseudo-schedule. The number of operations and aircraft types are both the same in the EDMS and AEDT 2b airport studies, but the times at which those aircraft operate will vary between the two models due to the way the random generator for the pseudo-schedule is applied. It is important to note that the overall schedule will follow the assigned operational profiles in AEDT 2b. In addition, due to the differences in the generation of the pseudo-schedule, aircraft operations may take different taxi-paths as well as take-off and land on different runways in the two models. These all are major contributors to the difference in the emission concentrations between AEDT and EDMS.

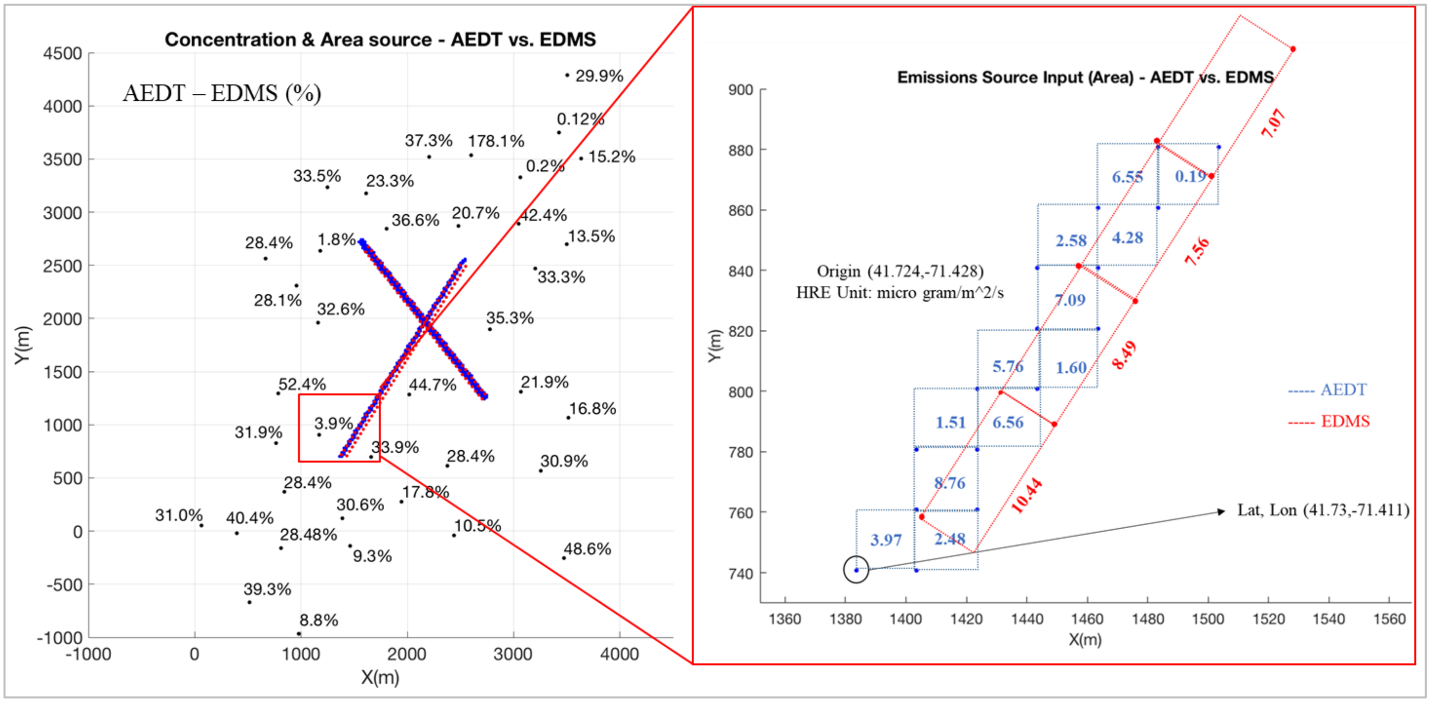


Figure 1: Concentration Comparison between AEDT and EDMS at Each Receptor

The comparison of emissions inventory results showed that there are differences. The differences associated with the emissions inventories are mainly attributed to aircraft sources. The main reason for differences between the aircraft sources is due to the fact that AEDT and EDMS use different fuel consumption models. In addition, there is some difference in the APM that may be causing some additional difference as well. Previous testing and comparisons of AEDT 2b to EDMS at the flight and segment level have shown that AEDT 2b produces higher fuel burn, specifically at climb-out and approach modes. This is aircraft-dependent and is the primary reason why fuel burn, CO2, H2O, SOx, and NOx emissions are higher for AEDT 2b than EDMS. Overall, the fuel burn, CO2, H2O, SOx, NOx, CO, HC, VOC, NMHC, and TOG emissions inventories comparison between AEDT 2b and EDMS show a certain degree of differences given the differences in the fuel burn models used by the two tools. The big difference in PM results mainly from the fact that AEDT doesn't have SN for some engines while EDMS does.

There are also differences between the pollutant concentrations reported by AEDT 2b and EDMS associated with air quality dispersion modeling. Dispersion results vary between EDMS and AEDT 2b due to the different fuel consumption calculated by the two models. Also, the area source size and orientations differ between the two models for ground and airborne sources. The different area sources in AEDT and EDMS lead to the difference in emission assignments for these two tools. Most importantly, operational profiles are utilized to distribute aircraft operations annually on a quarter-hour, daily, and monthly basis. However, due to the difference in how flights are handled computationally compared to EDMS, AEDT 2b and EDMS do not generate the same exact pseudo-schedule. Due to the differences in the generation of the pseudo-schedule, aircraft operations may take different taxi-paths as well as take-off and land on different runways in the two models.

With the exception of PM10 and PM2.5, the differences in pollutant concentrations of CO and NOx between AEDT 2b and EDMS are within an acceptable range. This indicates that the air quality dispersion functionality is operating as intended. The primary cause of any differences in the pollutant concentration results of AEDT 2b and EDMS are associated with fuel consumption models. The PM2.5 and PM10 concentrations mirror what was observed in the emissions inventory. AEDT 2b PM2.5 and PM10 concentrations are consistently lower than the EDMS results, which is partially due to PM values produced by AEDT are lower than EDMS since they used different method. AEDT uses FOA3.0 while EDMS uses FOA3.0a method to calculate PM. An additional analysis was conducted and showed that AEDT and EDMS produced similar PM results when they used the same PM calculation method (FOA3.0).

Comparison of INM and AEDT 2b for Noise Computation Functionality

The purpose of this Use study is to evaluate the capability in AEDT 2b to perform a Part 150 airport noise analysis, and to test other aircraft noise modeling functionality in AEDT 2b. Historically, Part 150 analyses were performed with the legacy INM tool. Since a key requirement for AEDT 2b was to sunset INM, Use Case D includes detailed comparisons between INM 7.0d su1 (the final version of INM) and AEDT 2b, to confirm that AEDT 2b performs as expected for Part 150 studies.

Additional noise-related functionality included in AEDT and INM, but not necessarily used for Part 150 analyses, was also evaluated. Several different airport studies were compared, in order to focus on different noise functionalities in the tools. A comparison of the AEDT 2b and INM 7.0d showed that the models have comparable noise results in most cases, although some differences were noted. GT's role in this study was to investigate the cause of the differences and communicate the findings back to the FAA and the AEDT development team. Each of the following subsections discusses the key causes of differences between INM.

Airport Weather

The default weather data used in AEDT resides in the airport database. Even when an INM study, with user-defined weather data (or even INM default weather data), is imported into AEDT, the AEDT data is utilized unless explicitly edited by the user in AEDT after the importation. Differences in weather data can result in differences in noise levels, even if default atmospheric absorption is used (SAE-AIR-1845). Of particular note is the headwind. INM assumes a default 8 kts headwind, whereas AEDT uses airport-specific headwind data.

One of the Part 150 like studies conducted for the ANC airport revealed the different noise results due to the differences in the weather. ANC was run in both INM 7.0d su1 and AEDT 2b.

Table 3 provides the DNL 55 to 85 dB contour areas from INM and AEDT. For the ANC study with bank angle turned on, the differences between the AEDT 2b and INM DNL contour area results were less than 6.3% for the contour areas of interest (with the difference for the DNL 65 dB DNL contour being 4.5%). A visual comparison of the contour plots in Figure 2 showed that the AEDT 2b and INM contours had similar shapes. At higher noise levels that produce smaller contour areas (e.g., 85 dB DNL), the differences became greater than 10%, but this is attributed to differences in contouring methods and contour resolution.

The observed differences in the noise results between INM and AEDT are caused by a combination of updates to the APM module, airport weather data, aircraft performance data, and different noise grid locations. The average temperature at ANC used in AEDT is much colder than the standard weather used in INM as shown in **Table 4**. The ANC study was rerun after modifying the AEDT weather to match the standard weather used in INM. The noise results in Table 5 show much better agreement in DNL contour areas between INM and AEDT with a 1.66% difference for DNL 65 dB.

Table 3. ANC – DNL with Bank Angle Testing Results

Level (dB)	INM (sq km)	AEDT (sq km)	Diff [INM -AEDT] (sq km)	Diff (%)
55	268.233	278.475	-10.242	3.6
60	94.780	101.163	-6.383	6.3
65	43.234	45.291	-2.057	4.5
70	20.246	20.992	-0.746	3.6
75	8.993	9.284	-0.291	3.1
80	3.919	4.069	-0.150	3.7
85	1.295	0.358	0.937	N/A[1]

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[1] At higher noise levels that produce smaller contour areas (e.g., 85 dB DNL), the differences between AEDT and INM contours often becomes large (greater than 10-20%). This is attributed to differences in contouring methods and contour resolution. In addition, AEDT does not plot contours that intersect the study boundary, which can be problematic when

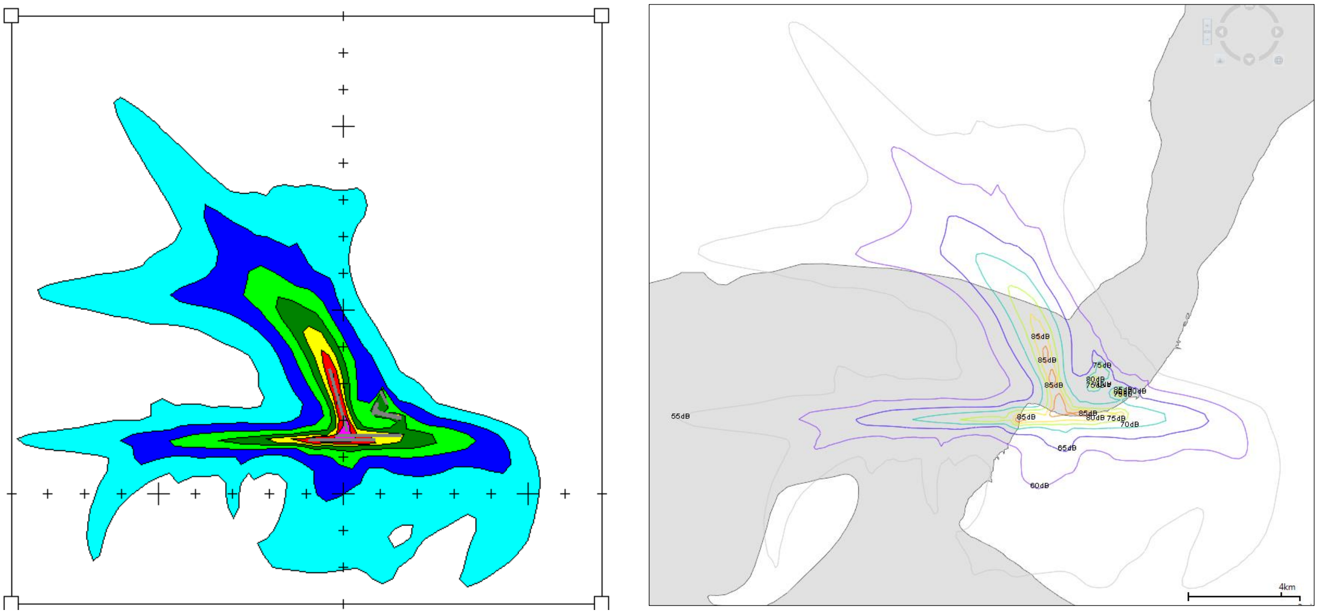

Figure 2. Comparison of the DNL Contours of the ANC Airport between INM (left) and AEDT 2b (right)

Table 4. ANC Annual Average Weather in AEDT 2b vs the Standard Weather in INM

Parameters	**AEDT 2b**	**INM 7.0**
Temperature(˚F)	36	59
Pressure (millibars)	1003.05	1013.2
Head Wind (knots)	6.34	8

Table 5. ANC – DNL with Bank Angle Testing Results after Matching the Airport Weather

Level (dB)	**INM (sq km)**	**AEDT (sq km)**	**Diff [INM -AEDT] (sq km)**	**Diff (%)**
55	268.233	266.021	2.212	-0.83
60	94.78	97.914	-3.134	3.20
65	43.234	43.965	-0.731	1.66
70	20.246	20.257	-0.011	0.05
75	8.993	8.989	0.004	-0.04
80	3.919	3.939	-0.02	0.51

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comparing large contour areas (e.g., 55 dB DNL). When these differences became greater than 50%, they were not included in this analysis, and they were earmarked to be revisited in the future, through an investigation of contour/grid resolution.

Contouring Algorithm
JFK was run in both INM 7.0d su1 and AEDT 2b with and without bank angle. All the results with the bank angle are presented in Table 6. For the JFK study with bank angle turned on, the difference between the AEDT 2b and INM DNL contour area results were less than 9.3% for the contour areas of interest (with the difference for the DNL 65 dB contour being 9.3%). However, several contours in AEDT 2b were unrealistically small (DNL 70 and 80 dB). After an investigation, it was found that the unrealistically small contours were caused by a bug in AEDT's contouring algorithm. The AEDT's contouring algorithm was found to work properly most of the time when the contour shapes are relatively simple. However, when contour shapes become complex due to multiple runways and turning tracks, the contouring algorithm could fail to capture all the features of a complex contour such as contour holes and islands. This bug was fixed for the AEDT 2c release.

Table 6. JFK – DNL with Bank Angle Testing Results

Level (dB)	**INM (sq km)**	**AEDT (sq km)**	**Diff [INM -AEDT] (sq km)**	**Diff (%)**
55	329.804	316.054	13.750	-4.4
60	140.853	140.707	0.146	-0.1
65	49.602	54.670	-5.068	9.3
70	20.426	0.011	20.415	N/A
75	9.644	9.905	-0.261	2.6
80	4.630	0.099	4.531	N/A
85	1.885	1.887	-0.002	0.1

Noise Grid Point Positions
AEDT and INM use slightly different methods for assigning grid point positions in a study. In both INM and AEDT, a set of fixed grids is created by defining the numbers of points being generated to X and Y directions from a reference point and the spaces among the points. The set of generated points forms a flat planar surface, and they are projected down to the Earth's surface to assign the latitude and longitude coordinates to each of the grid points. The X-Y plane of the grids and the Earth's surface make contact at a point, used as the projection origin. INM and AEDT use different projection origins to create this map projection. INM uses the airport origin as the projection origin, whereas AEDT uses the grid origin (the south-west corner of the X-Y plane). This can result in different coordinate locations for what is supposed to represent the same grid point, even if a grid is imported from INM. The differences in the grid coordinate locations don't necessarily impact noise contours as long as the grid resolutions are fine enough. However, care must be made when noise results are compared on a receptor point-by-receptor point basis. An update to AEDT 2c was made to use the airport reference point as the projection origin.

Impact of Enhancement in the APM Module to Noise Results
The flight path segmentation in AEDT and some additional functionalities in the APM are different from the segmentation and performance methods used in INM. This can result in small changes to flight path segment geometry, speed and thrust, which in turn can have small effects on noise levels. Please see Figure 5 in the next section for more details.

Engine Installation Locations
AEDT and INM calculate the directivity in lateral attenuation of noise accounting for engine installation locations for jet aircraft. In INM, the engine installation location values are associated with the spectral class database. Since separate spectral classes were used for approach and departure operations for any given aircraft, there existed the possibility that an aircraft could (incorrectly) have different engine installation directivity adjustments for approach and departure operations. This issue was resolved in AEDT with decoupling of engine installation location and spectral class. Therefore, only a single engine installation location is referenced for each aircraft, and therefore the same engine installation directivity adjustment is guaranteed to be used for approach and departure operations in AEDT 2b. However, this means that engine installation location value for several aircraft in the test cases used in this study are not consistent between AEDT and INM. Implications of the differences in engine installation locations are discussed in this section.

The different engine installation directivity adjustments are presented in Figure 3. Since separate spectral classes were used for approach and departure operations for any given aircraft, there existed the possibility that an aircraft could (incorrectly) have different engine installation directivity adjustments for approach and departure operations. If the incorrect engine installation location was assigned to an aircraft, the result could be a noise level difference of up to 1.9 dB, depending on the elevation angle.

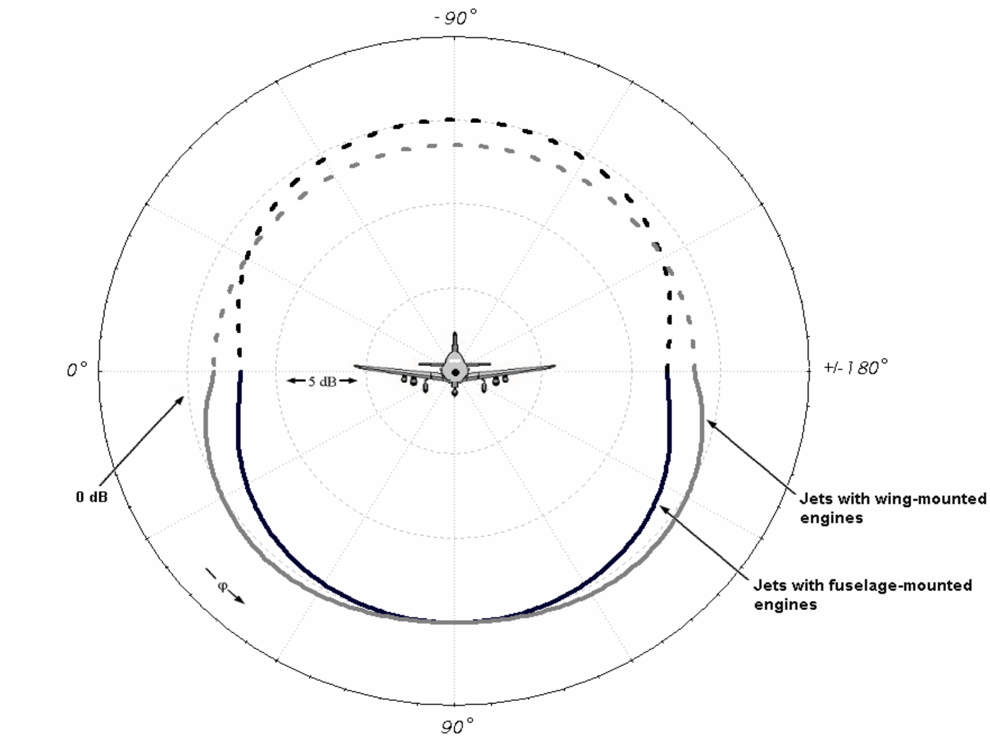


Figure 3. Illustration of Engine-Installation Effects for Jet-Powered Airplanes

This issue was resolved in AEDT with the decoupling of engine installation location and spectral class. Therefore, only a single engine installation location is referenced for each aircraft, and therefore the same engine installation directivity adjustment is guaranteed to be used for approach and departure operations in AEDT 2b. However, this means that several aircraft in the test cases used for AEDT UQ Use Case D do exhibit this issue. Those aircraft are listed in Table 7. As listed in the table, 26 INM aircraft types had different engine locations from the corresponding AEDT aircraft for either or both departures and arrivals. While AEDT corrected the inconsistent engine installation locations of the INM aircraft, the process also introduced errors in AEDT engine installation locations for some aircraft. INM aircraft 727100, 727EM1, 727Q15, 727Q7, and 727QF are Boeing 727-100 and 727-200 with various engine models. In INM, the engine locations of all of the Boeing 727s are correctly assigned as fuselage mounted. However, in AEDT, the engines of the corresponding aircraft types are incorrectly assigned as wing mounted.

Table 7. Aircraft with Engine Installation Location Differences in INM vs. AEDT

INM AIRCRAFT ID	AIRCRAFT DESCRIPTION	INM Eng. Location for Arrivals	INM Eng. Location for Departures	AEDT Eng. Location	Is AEDT Correct?
737	Boeing 737/JT8D-9	Fuselage	Wing	Wing	YES
717200	Boeing 717-200/BR 715	Wing	Fuselage	Fuselage	YES
727100	Boeing 727-100/JT8D-7	Fuselage	Fuselage	Wing	NO
727EM1	FEDX 727-100/JT8D-7	Fuselage	Fuselage	Wing	NO
727Q15	Boeing 727-200/JT8D-15QN	Fuselage	Fuselage	Wing	NO
727Q7	Boeing 727-100/JT8D-7QN	Fuselage	Fuselage	Wing	NO
727QF	UPS 727100 22C 25C	Fuselage	Fuselage	Wing	NO
737D17	Boeing 737-200/JT8D-17	Fuselage	Wing	Wing	YES
737QN	Boeing 737/JT8D-9QN	Fuselage	Wing	Wing	YES
CNA510	Cessna Mustang Model 510 / PW615F	Wing	Fuselage	Fuselage	YES
CNA55B	Cessna 550 Citation Bravo / PW530A	Wing	Fuselage	Fuselage	YES
CNA750	Citation X / Rolls Royce Allison AE3007C	Wing	Fuselage	Fuselage	YES
ECLIPSE500	Eclipse 500 / PW610F	Fuselage	Wing	Fuselage	YES
EMB170	ERJ170-100	Fuselage	Fuselage	Wing	YES
EMB175	ERJ170-200	Fuselage	Fuselage	Wing	YES
FAL20	FALCON 20/CF700-2D-2	Wing	Fuselage	Fuselage	YES
GIV	Gulfstream GIV-SP/TAY 611-8	Wing	Fuselage	Fuselage	YES
GV	Gulfstream GV/BR 710	Wing	Fuselage	Fuselage	YES
LEAR25	LEAR 25/CJ610-8	Wing	Fuselage	Fuselage	YES
MD81	MD-81/JT8D-217	Wing	Fuselage	Fuselage	YES
MD82	MD-82/JT8D-217A	Wing	Fuselage	Fuselage	YES
MD83	MD-83/JT8D-219	Wing	Fuselage	Fuselage	YES
MD9025	MD-90/V2525-D5	Wing	Fuselage	Fuselage	YES
MD9028	MD-90/V2528-D5	Wing	Fuselage	Fuselage	YES
MU3001	MU300-10/JT15D-5	Wing	Fuselage	Fuselage	YES
SABR80	NA SABRELINER 80	Wing	Fuselage	Fuselage	YES

In order to assess the noise impacts due to the changes in engine installation locations from INM to AEDT, SEL contour areas from single flight operations of a couple of aircraft types were compared. Five aircraft types of 737QN, MD81, SABR80, 727Q15, and 727Q7 were flown individually at the SFO airport in both INM and AEDT. For 737QN, MD81, and SABR80, the engine locations for the arrivals were incorrectly assigned in INM and were fixed in AEDT. Table 8, Table 9, and Table 10 provide comparisons of SEL contour areas of these three aircraft types between INM and AEDT. For 737QN, MD81, and SABR80, the differences in SEL contour areas were small for most dB levels. The tests showed that changes in engine installation locations for these three aircraft did not have a significant impact on noise results.

Table 8. SEL Contour Areas at SFO from a Single 737QN Arrival Flight

Level (dB)	INM (sq km)	AEDT (sq km)	Diff [INM -AEDT] (sq km)	Diff (%)
75	25.869	25.805	0.064	0.25
80	11.859	11.793	0.066	0.56
85	4.335	4.253	0.082	1.93
90	1.141	1.051	0.09	8.56

Table 9. SEL Contour Areas at SFO from a Single MD81 Arrival Flight

Level (dB)	INM (sq km)	AEDT (sq km)	Diff [INM -AEDT] (sq km)	Diff (%)
75	14.593	14.461	0.132	0.91
80	4.092	4.005	0.087	2.17
85	0.87	0.911	-0.041	-4.50
90	0.326	0.296	0.03	10.14

Table 10. SEL Contour Areas at SFO from a Single SABR80 Arrival Flight

Level (dB)	INM (sq km)	AEDT (sq km)	Diff [INM -AEDT] (sq km)	Diff (%)
75	18.095	18.062	0.033	0.18
80	8.886	9.02	-0.134	-1.49
85	4.276	4.291	-0.015	-0.35
90	1.63	1.604	0.026	1.62

On the other hand, the test results for 727Q15 in for an arrival and in Table 12 for a departure flight showed from 12% up to 20% differences in SEL contour areas. For both the departure and arrival cases, AEDT showed greater contour areas for all dB levels. Table 13 and Table 14 provide the LAMAX contour areas from a 727Q15 arrival and a departure flight at SFO. Similar to the SEL results, AEDT had about 13% greater contour areas for all dB levels. Figure 4 shows the SEL noise contours from a 727Q15 arrival at SFO calculated from INM and AEDT. Visual inspection of the contours from 70 to 95 dB reveals that the contours from AEDT (red) are larger than the contours from INM (blue), while the general shapes are very similar.

Table 11. SEL Contour Areas at SFO from a Single 727Q15 Arrival Flight

Level (dB)	INM (sq km)	AEDT (sq km)	Diff [INM -AEDT] (sq km)	Diff (%)
75	34.33	40.59	-6.26	-15.42
80	16.15	19.14	-2.99	-15.62
85	7.08	8.59	-1.51	-17.58
90	2.86	3.57	-0.71	-19.89

Table 12. SEL Contour Areas at SFO from a Single 727Q15 Departure Flight

Level (dB)	INM (sq km)	AEDT (sq km)	Diff [INM -AEDT] (sq km)	Diff (%)
75	304.91	346.36	-41.45	-11.97
80	194.32	223.75	-29.42	-13.15
85	96.81	114.96	-18.15	-15.79
90	39.44	46.99	-7.55	-16.07

Table 13. LAMAX Contour Areas at SFO from a Single 727Q15 Arrival Flight

Level (dB)	INM (sq km)	AEDT (sq km)	Diff [INM -AEDT] (sq km)	Diff (%)
75	8.4	9.71	-6.26	-13.49
80	4.36	5.06	-2.99	-13.83
85	2.06	2.4	-1.51	-14.17
90	0.92	1.07	-0.71	-14.02
95	0.4	0.46	-0.21	-13.04

Table 14. LAMAX Contour Areas at SFO from a Single 727Q15 Departure Flight

Level (dB)	INM (sq km)	AEDT (sq km)	Diff [INM -AEDT] (sq km)	Diff (%)
75	74.41	85.6	-6.26	-13.07
80	36.16	41.86	-2.99	-13.62
85	17.32	20.03	-1.51	-13.53
90	9.41	10.85	-0.71	-13.27
95	5.76	6.64	-0.21	-13.25

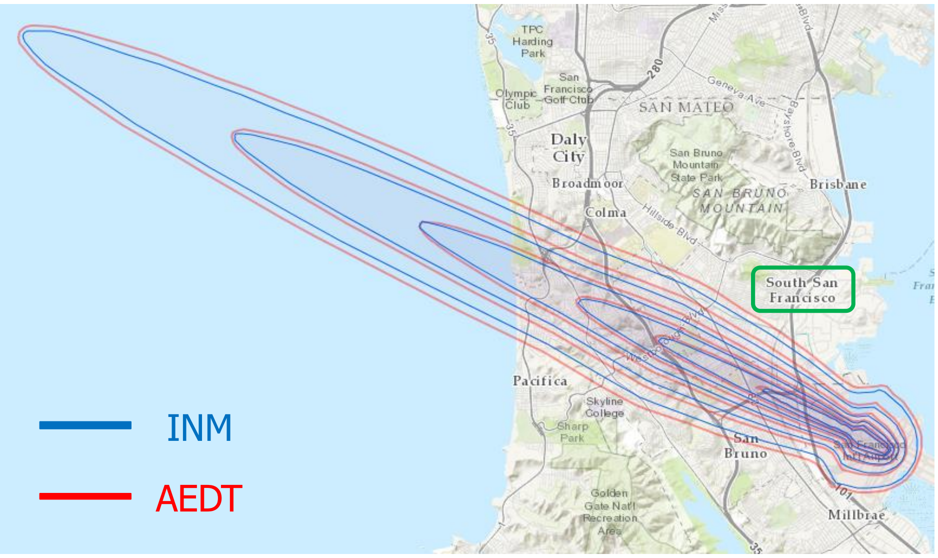


Figure 4. SEL Contour Comparisons for a 727Q15 Single Arrival Flight

To confirm that the differences in noise results are due to the different engine installation locations, a series of investigations were conducted. First, all the ANP coefficients of 727Q15 including aircraft performance characteristics, departure procedures, and NPD curves were compared and confirmed that they were all exactly the same. The INM and AEDT studies were set up at the SFO airport using the same airport weather, runway, flight track, and noise grid definitions. To see if differences in the APM were responsible for differences in the noise results, flight tracks from INM and AEDT were compared as well. Figure 5 shows comparisons of flight trajectories and thrust profiles from INM and AEDT. Both the altitude and thrust against ground distance profiles from INM and AEDT show a very close match to each other. The AEDT flight path had slightly more segments than the flight path from INM, which can improve accuracy of noise calculations. However, the differences in noise results due to the increased number of flight segments are less than 1%. Finally, the engine installation location of 727Q15 was temporarily corrected in AEDT's fleet database to accurately model the installation effect. After changing the engine location from wing to fuselage for 727Q15 in AEDT, the arrival and departure SEL 70 to 90 dB contour areas matched the INM results with less than 0.5% differences for all dB levels. This series of tests confirmed that the differences in noise results between 727Q15 between INM and AEDT were driven by the different engine installation locations.

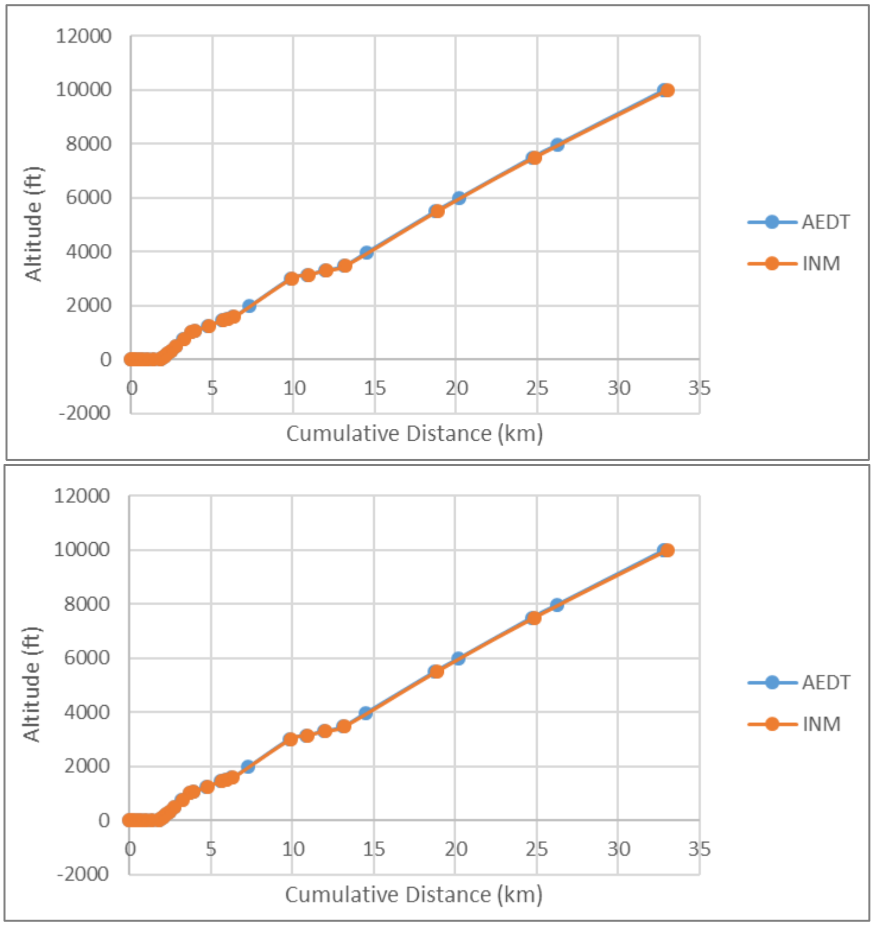


Figure 5. Comparison of Flight Trajectories and Thrust Profiles of a 727Q15 Departure from INM and AEDT

An additional test result is provided here to show the differences in the noise results when the engine locations between INM and AEDT are the same. 727D17 and 727Q9 are other Boeing 727 aircraft with different engine models than the 727Q15. For these two ANP aircraft, the engine locations are correctly assigned as fuselage in both INM and AEDT. Figure 6 depicts the SEL 70 to 95 dB contours for a 727D17 arrival from INM and AEDT. Table 15 compares the contour areas for the corresponding contours. The test results show that a model of 727-200 with consistent engine location can produce very similar noise results between INM and AEDT with less than 1% difference for all the SEL levels compared. The incorrect engine installation locations found in AEDT 2b have been fixed in the AEDT 2d release.

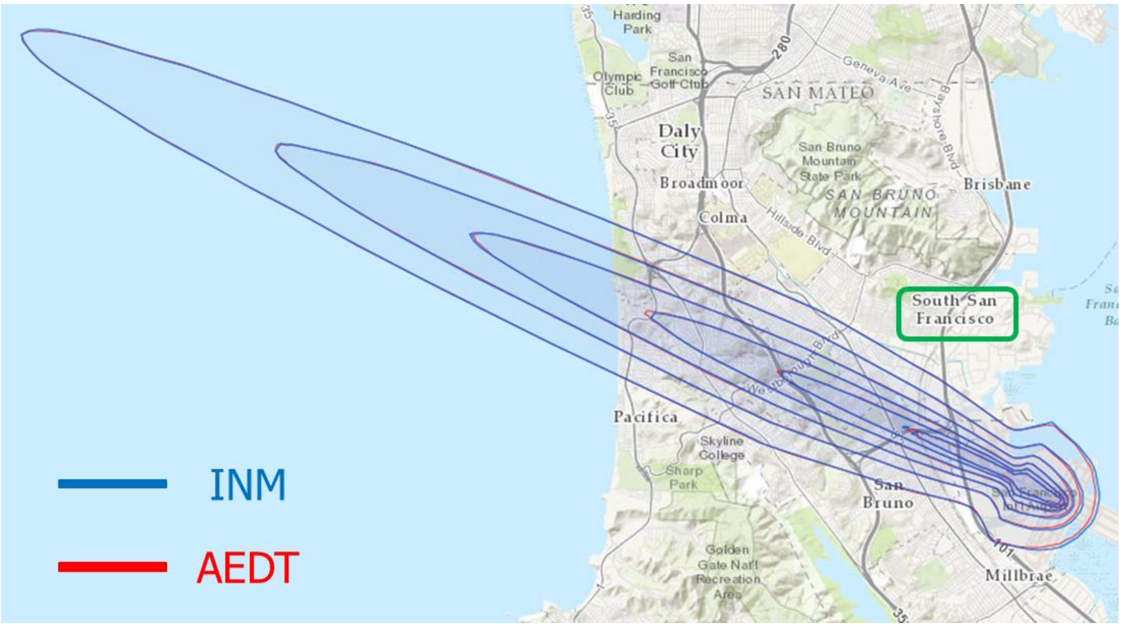


Figure 6. SEL Contour Comparisons for a 727D17 Single Arrival Flight

Table 15. SEL Contour Comparisons for a 727D17 Single Arrival Flight

Level (dB)	INM (sq km)	AEDT (sq km)	Diff [INM -AEDT] (sq km)	Diff (%)
70	71.387	70.972	0.415	0.58
75	36.644	36.431	0.213	0.58
80	18.023	17.905	0.118	0.66
85	7.881	7.882	-0.001	-0.01
90	2.983	2.957	0.026	0.88
95	0.87	0.862	0.008	0.93

Update to AEDT's Aircraft Performance and Noise Database (FLEET DB)

Updates to AEDT's aircraft performance and noise database can lead to different noise results. The AEDT's fleet database are constantly updated in order to incorporate the best available information. Since the INM database does not receive the same updates, improvements in the AEDT database can lead to differences in aircraft performance data (ANP coefficients) and noise data (NPD curves) between AEDT and INM.

Noise from Helicopter Taxi Operation

UCD-Helis is a simple airport study with helicopter operations that includes taxi operations. The study was run in both INM 7.0d su1 and AEDT 2b with bank angle. It should be noted that although UCD-Helis focuses on modeling helicopter operations, not all helicopters nor all helicopter profiles in the AEDT Fleet database were included in this analysis. This analysis is meant to check the noise computation functionality related to helicopters in AEDT, and not specifically review the contents of the AEDT 2b databases. The DNL noise results from INM and AEDT are compared in Table **16**.

Table 16. UCD-Helis – DNL with Bank Angle Phase 2 Testing Results

Level (dB)	INM (sq km)	AEDT (sq km)	Diff [INM -AEDT] (sq km)	Diff (%)
55	175.579	176.575	-0.996	0.6
60	81.555	82.447	-0.892	1.1
65	4.278	5.008	-0.730	14.6
70	0.585	0.583	0.002	-0.3
75	0.237	0.237	0.000	-0.2
80	0.097	0.101	-0.004	4.0
85	0.036	0.033	0.003	-8.3

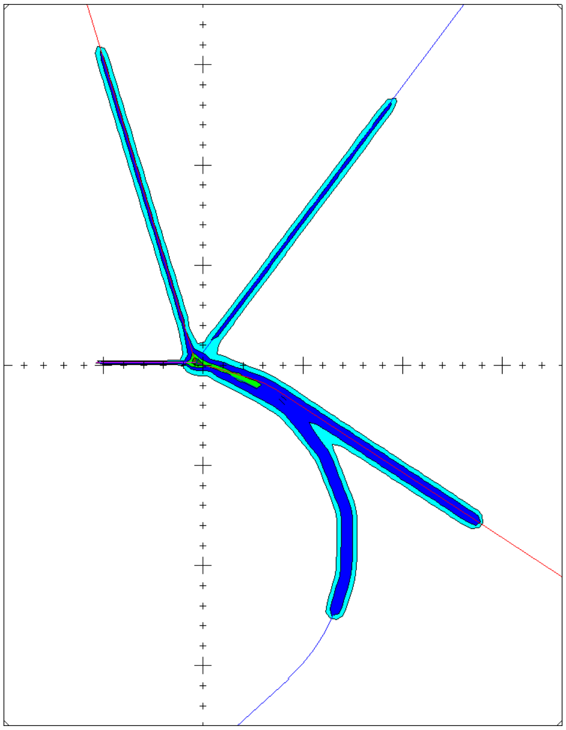


Figure 7. UCD-Helis – DNL with Bank Angle INM Contours

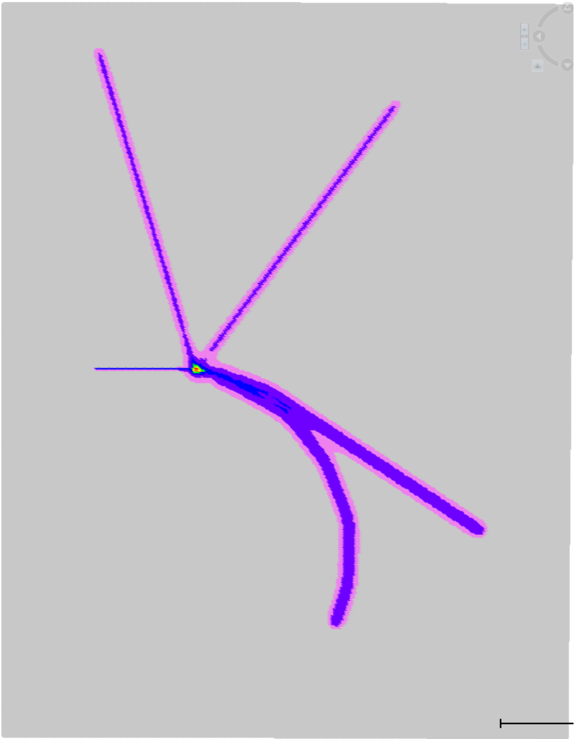


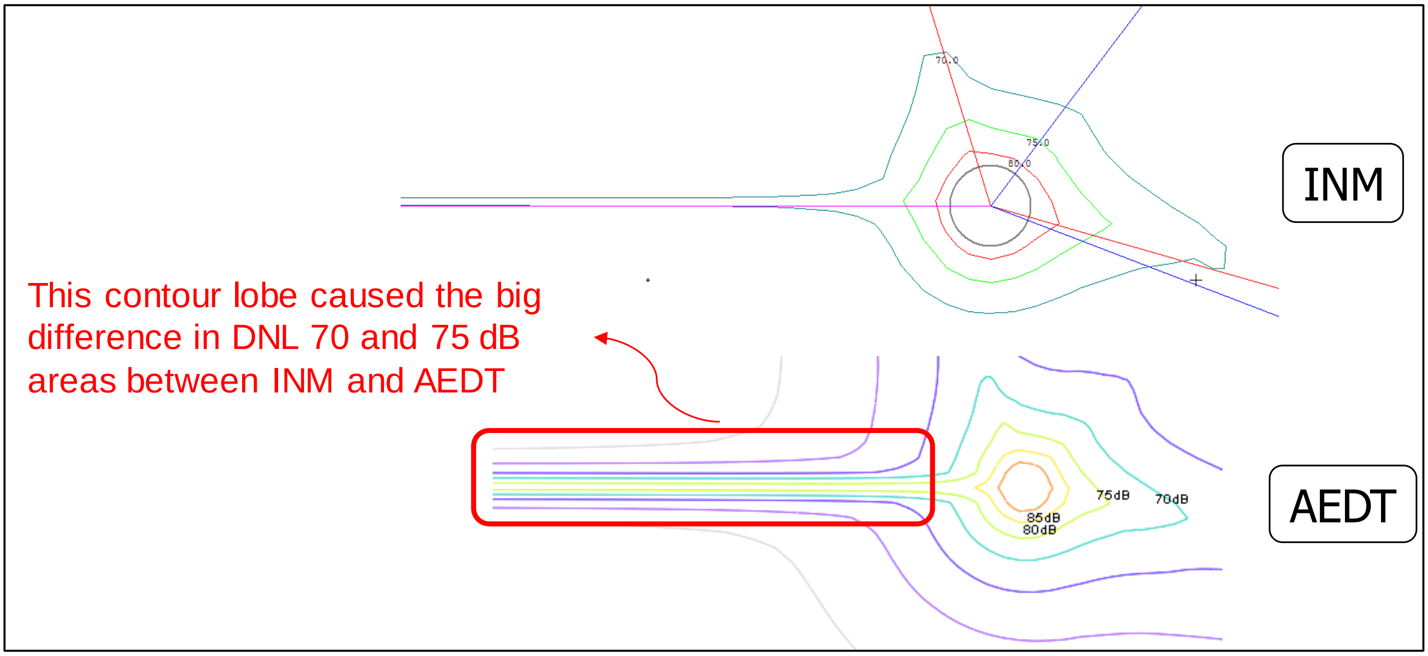
Figure 8. UCD-Helis – DNL with Bank Angle AEDT 2b Contours

For UCD-Helis, the differences between the AEDT 2b and INM DNL contour area results were less than 14.6% for the contour areas of interest. The 65 dB DNL contour results showed a difference of 14.6% between INM and AEDT 2b, and shows the largest contour area difference for this study. A visual comparison of the contour plots showed that the AEDT 2b and INM contours have similar shapes except for one small 65 dB DNL contour island.

After an investigation, a couple of reasons were identified to have caused the differences in the noise results. First, the update to the AEDT airport weather database caused differences in the results. While INM used the standard atmosphere, AEDT used the annual average weather at the Central Wisconsin airport. The annual average temperature at the Central Wisconsin airport was 43 degrees Fahrenheit. In addition, the differences in the noise grid locations combined with insufficient grid resolution have also contributed to the differences in the noise results. As mentioned in a previous section, differences in noise grid location due to different grid map projection methods in INM and AEDT 2b do not necessarily cause differences in contour areas as long as the grid resolution is fine enough. The spacing of the grid points used in the initial analysis was 0.8 nm, which is sufficient for a typical airport noise study. However, since the UCD study had a small number of helicopter operations, a finer resolution was necessary. Therefore, the study was rerun after updating the airport weather in INM and decreasing the grid spacing to 0.2 nm from 0.8 nm. The updated results are presented in Table 17. The differences in contour areas decreased after rerunning the study except for 70 and 75 dB. Visual inspection of the updated contour plots showed that differences in the small westerly contour lobe caused these contour areas differences. Figure 9 provides comparisons of the westerly lobe between INM and AEDT. This westerly lobe is due to a taxi operation of a Bell 212 helicopter. INM correctly modeled this taxi operation using a taxi track and a taxi procedure. However, AEDT modeled this operation as a departure operation while using the same taxi track. Assigning an incorrect operation type in AEDT caused the Bell 212 to use the maximum takeoff thrust instead of the idle thrust for this taxi operation. This bug in AEDT caused greater DNL 70 and 75 dB areas. This issue was reported to the AEDT development team and was resolved in the AEDT 2d release.

Table 17. UCD-Helis – DNL with Bank Angle Phase 2 Testing Results after matching the Weather and increasing Grid Resolution

Level (dB)	INM (sq km)	AEDT (sq km)	Diff [INM -AEDT] (sq km)	Diff (%)
55	176.509	176.264	0.245	-0.1
60	83.432	83.336	0.096	-0.1
65	5.959	5.889	0.07	-1.2
70	1.033	1.097	-0.064	5.8
75	0.248	0.449	-0.201	44.8
80	0.108	0.105	0.003	-2.9
85	0.047	0.045	0.002	-4.4



This contour lobe caused the big difference in DNL 70 and 75 dB areas between INM and AEDT

Figure 9. UCD-Helis – DNL with Bank Angle AEDT 2b Contours

Task #2: Validation and Verification of BADA4 Implementation

Georgia Institute of Technology

Objective(s)

The FAA has incorporated BADA4 as part of the AEDT Fleet DB. This task focuses on a fleet wide environmental V&V effort to assess the implications of BADA4 from the historical Fleet DB. GT will ensure that the BADA4 algorithm and associated data are properly incorporated into AEDT by performing investigation at flight segment, entire flight, and airport level tests. The BADA4 performance results will be compared to the results using ANP model for terminal area operations. The

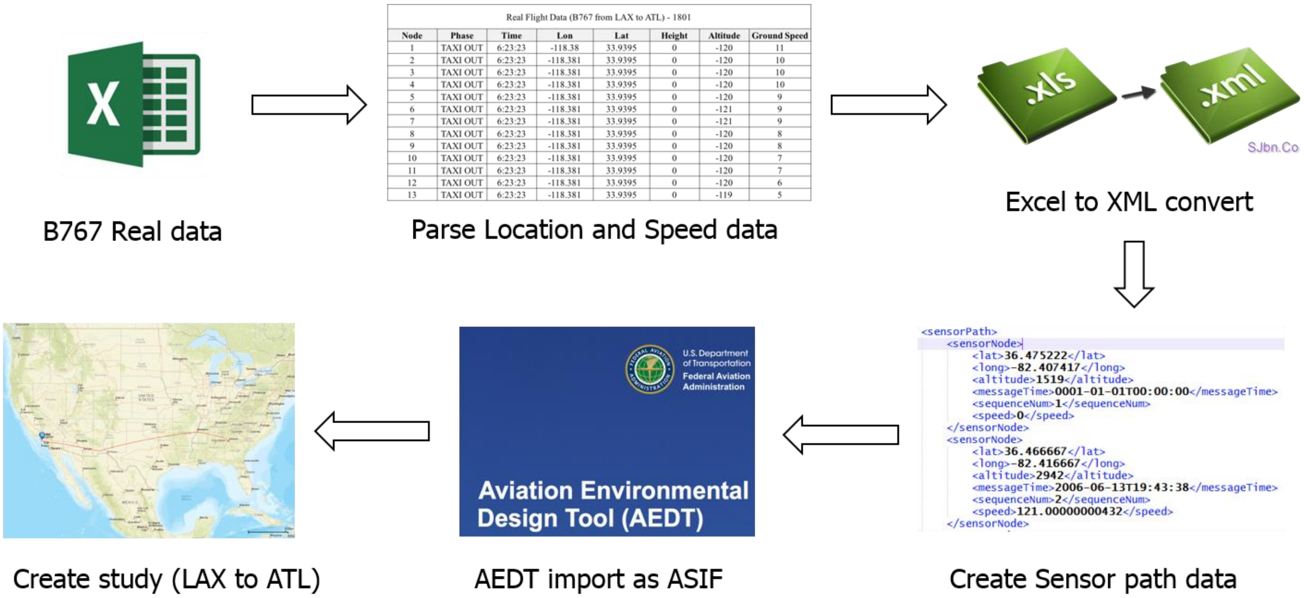
BADA4 performance results will be compared to the results using BADA3 for en-route operations. The environmental impacts that is fuel burn, emission, and noise results, using BADA4 will be compared to the results from using BADA3, ANP, and Senzig-Fleming-Iovinelli (SFI) methods.

Research Approach

Sensor Path Flight in BADA4

Base of Aircraft Data Family 3 (BADA3) method has been widely used for aircraft performance and fuel consumption in AEDT. Although BADA3 works well in the cruise region, it is well known that BADA3 is not optimized for terminal area operations. For this reason, AEDT uses BADA3 for an altitude above 10,000 feet and Aircraft Noise and Performance (ANP) method for an altitude below 10,000 feet.

In order to address the drawbacks of BADA3 in the terminal area, the high fidelity Base of Aircraft Data Family 4 (BADA4) has been developed. Currently in AEDT, BADA4 model only works for the sensor-path flights which is based on trajectory-driven flight performance. To understand how AEDT models sensor path flights, AEDT related documents were reviewed to determine how to create a sensor-path flight study in AEDT by the method shown in Figure 10.



Real Flight Data (B767 from LAX to ATL) - 1801

Node	Phase	Time	Lon	Lat	Height	Altitude	Ground Speed
1	TAXI OUT	6:23:23	-118.38	33.9395	0	-120	11
2	TAXI OUT	6:23:23	-118.381	33.9395	0	-120	10
3	TAXI OUT	6:23:23	-118.381	33.9395	0	-120	10
4	TAXI OUT	6:23:23	-118.381	33.9395	0	-120	10
5	TAXI OUT	6:23:23	-118.381	33.9395	0	-120	9
6	TAXI OUT	6:23:23	-118.381	33.9395	0	-121	9
7	TAXI OUT	6:23:23	-118.381	33.9395	0	-121	9
8	TAXI OUT	6:23:23	-118.381	33.9395	0	-120	8
9	TAXI OUT	6:23:23	-118.381	33.9395	0	-120	8
10	TAXI OUT	6:23:23	-118.381	33.9395	0	-120	7
11	TAXI OUT	6:23:23	-118.381	33.9395	0	-120	7
12	TAXI OUT	6:23:23	-118.381	33.9395	0	-120	6
13	TAXI OUT	6:23:23	-118.381	33.9395	0	-119	5

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        <long>-82.407417</long>
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    </sensorNode>
    <sensorNode>
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        <long>-82.416667</long>
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        <sequenceNum>2</sequenceNum>
        <speed>121.00000000432</speed>
    </sensorNode>
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Figure 10: Pre-processing for ASIF import into AEDT

As can be seen in Figure 10, a few important parameters for creating a sensor path in AEDT from a flight data recorder (FDR) data of B767 were parsed as the first step. Using those parameters, a table in Excel was generated and converted into an XML file. The sensor nodes created from the table were combined into the sensor path for the case study. For the next step, the sensor path file was imported into AEDT with ASIF import option. Finally, a study was created in AEDT which was a flight from Los Angeles International Airport (LAX) to Hartsfield-Jackson Atlanta International Airport (ATL). In terms of the runway assignment defined in the sensor path, the location information from the FDR data was investigated to assign a proper runway for both departure and arrival. After the flight track was created in AEDT, the ANP 767300 aircraft was chosen to compare with FDR data with respect to fuel consumption.

In order to model the study as exact as possible, the take-off weight for AEDT was changed to match with the FDR data. Additionally, the Modern-Era Retrospective analysis for Research and Application version 2 (MERRA-2) was used as AEDT's high-fidelity weather model. Lastly, smoothing and filtering of the data was performed to create the sensor path.

Investigation of BADA4 APM (by comparing with BADA3 and FDR data)

In this task, a validation and verification study was conducted to investigate the implementation of BADA4 performance model in AEDT. The BADA4 results were compared against FDR data tabulated as below. In order to protect the flight identity, the exact aircraft variant and day of the flight are not included. Four different cases were created in order to estimate important factors for accurate simulation results. For example, case 4 represents the result for the simulation setup which used SPI tool for data smoothing and filtering, MERRA-2 as high-fidelity weather, and real takeoff weight to reduce the gap between FDR and AEDT data. In terms of the results of fuel burn, AEDT provided the results for all test cases and fuel burn for FDR was calculated from the FDR fuel burn data. For case 4, as can be seen, the difference between FDR and BADA4 implementation on AEDT is 7.6%. This comparison shows the importance of data filtering, takeoff weight, and hi-fidelity weather required for accurate fuel consumption prediction in AEDT.

Table 18: Fuel consumption comparison (BADA4 vs. FDR)

	SPI	Weight	MERRA-2	Fuel Burn (kg)	Difference
FDR				19,182	N/A
Case 1				18,576	- 3.2 %
Case 2	Y			18,547	- 3.3 %
Case 3	Y	Y		21,393	11.5 %
Case 4	Y	Y	Y	20,642	7.6 %

In order to compare the FDR thrust data with AEDT, the location data with latitude and longitude was converted into a distance because the FDR data didn't have cumulative distance information. The result of the comparison between BADA3, BADA4, and FDR with respect to net corrected thrust versus cumulative distance is shown below.

Figure 11: Net corrected thrust (per engine) vs. Cumulative distance (BADA3 vs. BADA4 vs. FDR)

In Figure 11, BADA4 was more exact than BADA3 compared to the FDR data under same conditions such as same flight track and aircraft. However, it was also found that the terminal area for both departure and arrival was quite different between BADA and FDR data. The reason why there was a discrepancy will be further investigated by using high fidelity validation data in the near future.

Thrust vs N1 Analysis

In order to compare the results of AEDT with real world data, FDR data was obtained. This data is available in a tabular format and contained detailed information from the aircraft's sensors including the phase of the flight, time, position, engine parameters, aircraft control inputs, wind and weather data. The time resolution of the data is once per second. The only information available is the aircraft type and the origin-destination airports.

Although the FDR data includes a lot of detailed parameters, it does not include any direct measure of thrust. Thrust is one of the most important parameters that affects noise and emissions. When comparing BADA3 or BADA4 to FDR data, matching the thrust is imperative to ensure a match of real world emissions and noise footprint. Therefore, methods for obtaining thrust from the available parameters in the FDR data were investigated. The available engine parameters are fuel flow and fan rotation speed for each engine.

A method to estimate thrust from corrected fan speed, altitude and temperature is included in INM 7.0 Technical Manual. The formulation, known as the General Thrust equation is given as

$$\frac{F_n}{\delta} = E + FV_c + G_a A + G_b A^2 + HT + K_2(N1_c) + K_3(N1_c)^2 \tag{1}$$

$$N1_c = \frac{N1}{\sqrt{\theta}}$$

Where

$N1$ is proportional to the engine's fan rotation speed and is measured in percentage
θ is the temperature ratio
$N1_c$ is the corrected measure of the engine's fan rotation speed in percentage
$\frac{F_n}{\delta}$ is the net corrected thrust
V_c is the speed of the airplane
A is the altitude
T is the temperature
$E, F, G_a, G_b, H, K_2, K_3$ are all engine/aircraft specific coefficients

Given the coefficients and the operating conditions, the net corrected thrust was obtained using the formulations above. The INM manual includes the coefficients for 27 aircraft. A comparative visualization of the thrust dependence on engine fan speed is shown in Figure 12. It was observed that the dependence is mostly linear ($R^2 = 99.5\%$) with all aircraft reaching full thrust at 100% fan speed as expected. The different coefficients for each aircraft lead to different slopes. It is important to note that Figure 12 is based on sea-level and static conditions. For each of the aircraft, $V_c = 0$ and $A = 0$ in the formulation above.

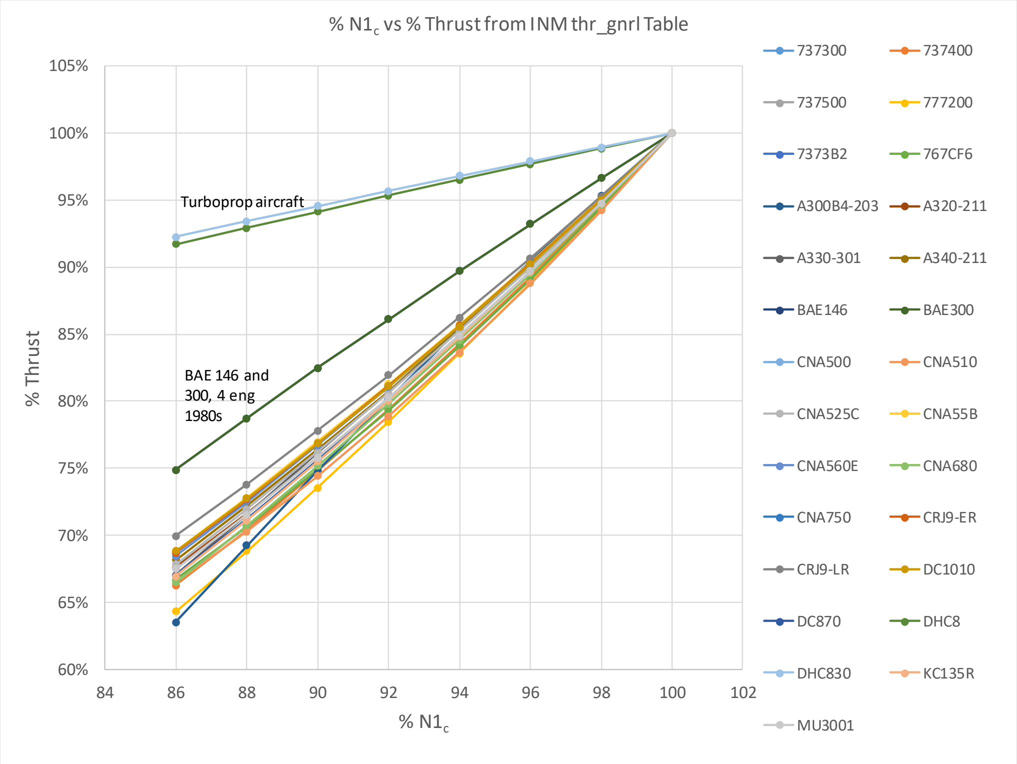


Figure 12: Thrust dependence on engine fan rotational speed, sea-level static conditions

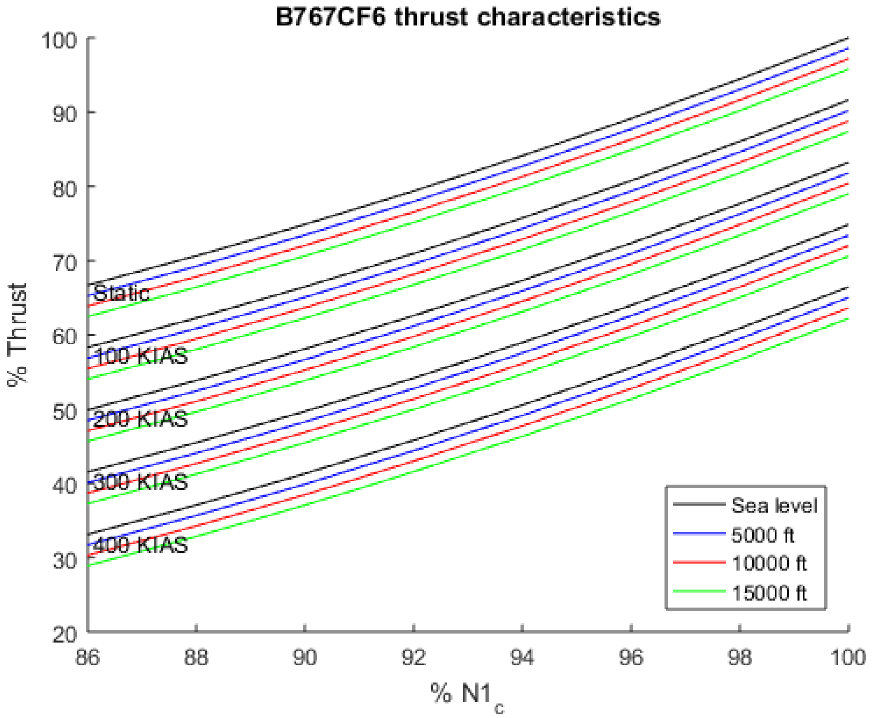


Figure 13: Thrust dependence on fan rotational speed, varying speed and altitude

In order to study the dependency on altitude and speed, the same formulation was applied to a single aircraft (B767CF6 in the ANP database) with a number of combinations of speed and altitude. The results are depicted in Figure 13. It was observed that the general shape of the curve remains the same. The effect of speed and altitude is to shift the curve up or down. Each color represents a particular altitude. The five distinct sets of 4 lines represent different airspeeds measured in KIAS (Knots, Indicated Air Speed). In order to estimate the net corrected thrust, we need to identify the aircraft's indicated airspeed and the altitude it is flying at. An increase in either altitude or speed shifts the curve downwards. This indicates a lower thrust for the same fan rotation speed if the speed or altitude is higher which is as expected.

Since the FDR has altitude and speed data included, the formula to calculate the thrust could be directly used for each engine at every point in the flight. For comparison, the average of the thrust from the two engines was used.

In this situation, coefficients were readily available for the aircraft in question. This may not always be the case and a more general method to estimate thrust may be required in the future. One way to work around this is to exploit the linearity of the thrust dependence. Eliminating the outliers and fitting a linear model across all jet aircraft types in Figure 12 one can obtain a method to estimate the thrust for any modern jet aircraft at a sea level static condition. The results are shown in Figure 14. While this model only holds for a sea-level static condition, it can be extended in a similar way to include varying speed and altitude conditions as well.

There is a limitation to this formulation. The technical manual for INM 7.0 states that the General Thrust coefficients should be valid up to 16,000 ft. The same coefficients have been used throughout the flight and hence the calculated thrust may not be valid at higher altitudes, particularly for cruise.

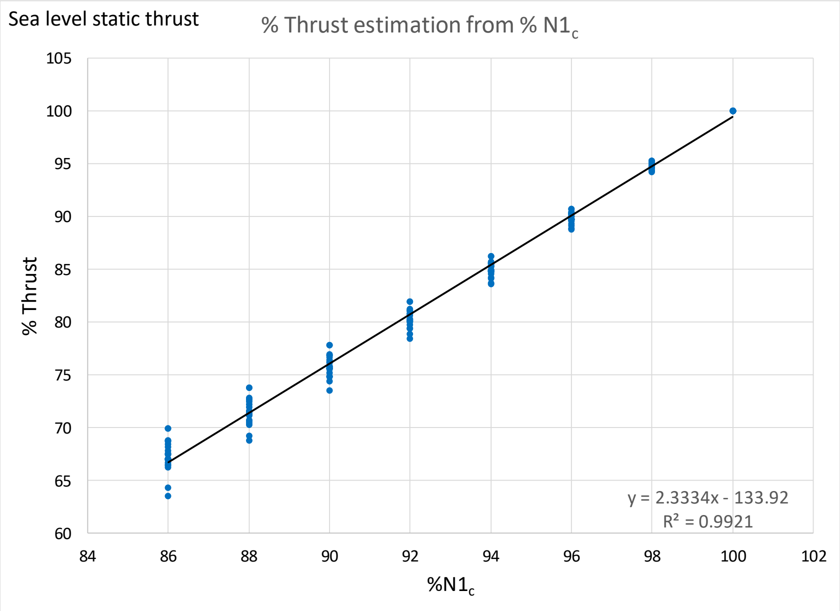


Figure 14: Linear model of thrust dependence on engine fan rotational speed, sea-level static condition

Task #3: Capability Demonstration and Validation of AEDT 2c and 2d Functionality

Georgia Institute of Technology

Objective(s)

For each of the AEDT 2c and 2d service pack releases, the scope of the UQ effort identifying the key changes to the AEDT versions from the previous releases was formulated. Depending on the type of updates incorporated, it would be necessary to identify the key sources of uncertainties and the best approach to conduct V&V and parametric uncertainty analysis. Depending on the analysis scope of the V&V, Parametric UQ can be optional. The outcome of this task is the definition of analysis scope, required tools, required data, V&V method, Parametric UQ method, and a list of input parameters to vary and their uncertainty bounds. Due to the dynamic nature of the agile AEDT development process, it is important that the research team remains flexible in the choice of the V&V approach and the work scope. The best available methods and data will be used in order to ensure accuracy and functionalities of future AEDT versions based on the discussion with the FAA/AEE.

A V&V and capability demonstration was conducted of the newly released AEDT versions. The analysis in this task can take a couple of different approaches depending on the type of updates and data availability. In the past UQ efforts, one of the most important methods of ensuring confidence in the tool capability was to conduct a use case(s) using both legacy tools and the new AEDT release and compare the results. This method would be the most appropriate way whenever a legacy tool has the same or similar functionalities and a validated use case has been modeled in that legacy tool. When the new functionality of AEDT does not exist in the legacy tools, the V&V exercise should use direct comparisons to the results generated by the mathematical algorithms behind the newly added functionality and/or real world data whichever available.

Research Approach

In order to provide the best possible environmental impacts modeling capabilities, the FAA/AEE continues to develop AEDT by improving existing modeling methods and data and adding new functionalities. The AEDT development team led by Volpe has been exercising the agile development process, as shown in Figure 15, where minor updates are released in a new Sprint version every three weeks. Major updates and/or new functionalities are incorporated as new service packs or feature packs in about a three months cycles as shown in Figure 15. An AEDT development cycle includes rigorous testing of all levels of software functionality from the individual modules to the overall system. However, the FAA/AEE seeks a robust uncertainty quantification effort in addition to this test program.

Figure 15: The Agile Methodology [Source: http://www.screenmedia.co.uk]

Table 19: AEDT Development and Public Release Schedule

Dates	Milestones
5/1/2016	Project Start
6/13/2016	AEDT 2b SP3 Release
9/12/2016	AEDT 2c Release
12/5/2016	AEDT 2c SP1 Release
3/13/2017	AEDT 2c SP2 Release
9/27/2017	AEDT 2d Release
3/2018	AEDT 2e Release
7/30/2018	Project End

For each of the AEDT version and service pack releases, GT reviewed the AEDT requirement documents and AEDT release notes to identify the key features and functionalities that need to be tested. During the period of January 2017 to October 2017, two public version of AEDT were released – including AEDT 2c SP2, and AEDT 2d, as listed in Table 19.

The main features/capabilities that were added to AEDT during the period include the following:

- Enhanced nvPM
- VALE Reporting with MOVES
- Runup Operation of Military Aircraft
- Open Contours
- Vector Tracks
- Track Dispersion
- Contour Combination
- Dynamic Grid
- Detailed Noise
- Bulk Operation Creation

The V&V and capability demonstration of the new features listed above are either completed or in progress.
Starting from January 2017, all the new AEDT sprint releases including Sprints from 80 to 94 have been tested. Sprints 80 – 94 included two public releases of AEDT, namely AEDT 2c SP2, and AEDT 2d. Fifteen sprint releases of AEDT focusing on new features and capabilities added have also been tested. Some of the new features/capabilities were minor updates to

the GUI, bug fixes or data updates. Major updates included enhanced nvPM, VALE reporting with MOVES, runup operation of military aircraft, open contours, vector tracks, track dispersion, contour combination, dynamic grid, detailed noise and bulk operation creation.

In order to understand the background of new AEDT features, the relevant documents were reviewed including the software requirement documents, Database Design Documents (DDD), AEDT sprint release notes, updated technical manual [8, 9], user manual [10, 11], and research papers/reports [12-15]. Basic testing of all the new AEDT versions to confirm its functionality have been performed. While some of the tests are in progress, the next subsections discuss the current progress and findings in more details.

Enhanced nvPM

Currently, the enhanced nvPM is a hidden feature that needs to be activated in the debug mode or using a hash key. In the enhanced nvPM capability implemented for AEDT 2c and 2d, the correlation options are implemented for estimating nvPM mass and number. And a new modeling methodology for estimating cruise nvPM mass and number is utilized based on CAEP's guidance. In addition, the nvPM system loss correction method for assessing particle losses that occur in the sampling system that measures the nvPM mass and number at the end of the sampling system is also implemented as one part of the enhanced nvPM features.

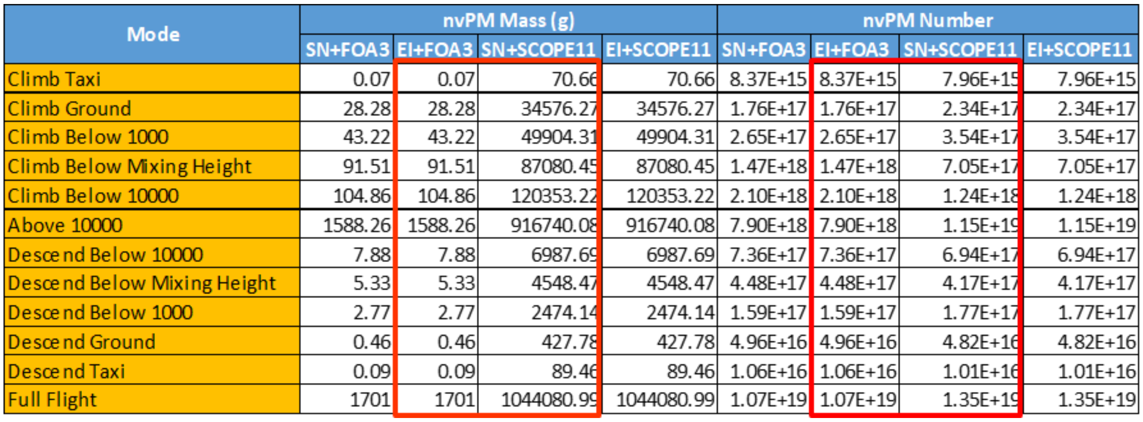
In the current implementation, there are four enhanced nvPM methods in AEDT including full-flight aerodyne-only, full-flight smoke number, full-flight emission index, and full-flight smoke number-aerodyne hybrid methods. The two correlation options SCOPE11 and FOA3 are only available for the full-flight smoke number and full-flight emission index methods. And the system loss correction method is only applicable to the correlation method of SCOPE11.

Since the enhanced nvPM function is not included in the public released version, a special version of AEDT needs to be used to demonstrate and test this feature. The special version (92.0.6001.1) was obtained by the research team and a test study to conduct the UQ analysis on the enhanced nvPM capability. The features related to this capability that were tested include correlation option, altitude adjustment, system loss correction factor, and other nvPM methods. And the tests utilized the system requirements document agreed by AEE on 8/3/2017 as a guideline.

Correlation Option

Based on the system requirements document, correlation options are enabled for Full-Flight Smoke Number and Full-Flight Emission Index method. This was tested and it worked as expected. There is a minor issue that when a user copies a metric with SCOPE11 correlation option, the option is not correctly copied, instead, FOA3 is copied. The two correlation options were further tested for nvPM mass and number, and Table 20 shows the nvPM results. It can be seen that regardless the nvPM methods used, the nvPM results are identical for the same correlation option, which might be a bug and is currently being investigated. Comparing SCOPE11 and FOA3, the difference in nvPM mass is huge, however nvPM number calculated by these two methods have same magnitude. Further investigation found that the unit for SCOPE11 is micro gram instead of gram which will be corrected.

Table 20: AEDT Development and Public Release Schedule



Mode	nvPM Mass (g)				nvPM Number			
	SN+FOA3	EI+FOA3	SN+SCOPE11	EI+SCOPE11	SN+FOA3	EI+FOA3	SN+SCOPE11	EI+SCOPE11
Climb Taxi	0.07	0.07	70.66	70.66	8.37E+15	8.37E+15	7.96E+15	7.96E+15
Climb Ground	28.28	28.28	34576.27	34576.27	1.76E+17	1.76E+17	2.34E+17	2.34E+17
Climb Below 1000	43.22	43.22	49904.31	49904.31	2.65E+17	2.65E+17	3.54E+17	3.54E+17
Climb Below Mixing Height	91.51	91.51	87080.45	87080.45	1.47E+18	1.47E+18	7.05E+17	7.05E+17
Climb Below 10000	104.86	104.86	120353.22	120353.22	2.10E+18	2.10E+18	1.24E+18	1.24E+18
Above 10000	1588.26	1588.26	916740.08	916740.08	7.90E+18	7.90E+18	1.15E+19	1.15E+19
Descend Below 10000	7.88	7.88	6987.69	6987.69	7.36E+17	7.36E+17	6.94E+17	6.94E+17
Descend Below Mixing Height	5.33	5.33	4548.47	4548.47	4.48E+17	4.48E+17	4.17E+17	4.17E+17
Descend Below 1000	2.77	2.77	2474.14	2474.14	1.59E+17	1.59E+17	1.77E+17	1.77E+17
Descend Ground	0.46	0.46	427.78	427.78	4.96E+16	4.96E+16	4.82E+16	4.82E+16
Descend Taxi	0.09	0.09	89.46	89.46	1.06E+16	1.06E+16	1.01E+16	1.01E+16
Full Flight	1701	1701	1044080.99	1044080.99	1.07E+19	1.07E+19	1.35E+19	1.35E+19

Altitude Adjustment

The enhanced nvPM capability allows the user to enable/disable altitude adjustment for flights below 3000 feet above ground level (AGL). This feature is tested for the SCOPE11 correlation method. However, the results show that SCOPE11 method produced the exactly same results for the cases with and without altitude adjustment. Further tests were conducted using FOA3 method. The results show that with altitude adjustment, FOA3 method produced more nvPM mass and number for most of the modes. One issue is that for two of the modes, even FOA3 method with altitude adjustment generated more nvPM mass, however, the nvPM number is less than the case without altitude adjustment. This is an issue that will be investigated and fixed.

System Loss Correction Factor

Based on the system requirements document, the system loss correction factor can be enabled/disabled for SCOPE11, and should not be available for FOA3 method. However, it was found that the following issues exist in this feature and will be fixed in the future:

- When the emission report is generated for a metric with “SCOPE11” option, the system loss correction box will be enabled for all emission report, and vice versa
- And for the metric with “FOA3” option, check the system loss correction box will double the nvPM results in emission report
- The “Apply System loss correction factors to nvPM results” checkbox is correlated between different emission reports
- System loss is not unselected by default if it was selected in a metric previously

Other Methods

To fully test the enhanced nvPM capability, other nvPM methods including full-flight Aerodyne-only and full-flight smoke number-Aerodyne hybrid methods were also tested. The results show that the hybrid methods generate reasonable results for nvPM mass and number. However, for full-flight aerodyne method, negative values were generated for nvPM mass for some of the modes, which is most likely due to the interpolation algorithm and will be fixed.

MOVES and AEDT Integration, and VALE Reporting

The Environmental Protection Agency (EPA) Motor Vehicle Emissions Simulator (MOVES) model is used to generate emissions inventories and/or AERMOD input files for on-road or off-road mobile sources. Although MOVES is not integrated in AEDT, a feedback mechanism is established through the AEDT Graphical User Interface (GUI). This mechanism provides the user an ability to feed the required link-based inputs needed by MOVES. The MOVES modeled link-based and aggregated emissions can then be fed back to AEDT. Link-based MOVES inputs are provided in AEDT GUI through the mobile-source layout components: roadways, parking facilities, and construction zones, in the Airport Layout.

Design and Export MOVES Links

To model roadway, parking facilities and construction zones using MOVES, users can create mobile-source layout components by using the Airport Layout Design feature in AEDT and then export the link-based inputs to MOVES for further modeling. After the MOVES link-based inputs are imported into MOVES, users can use MOVES to conduct project-level analysis, thus, mobile-source emissions inventory can be generated for the imported links. Once the MOVES emissions output for each link are obtained or the aggregated emissions by category, they can then be imported back into AEDT for integrating with other analysis.

The design of MOVES links was tested using the airport layout design feature in AEDT. This function works properly. Users can design MOVES links for roadway, parking facility, and construction zone. After the links were designed, they can be exported in the selected airport layout as MOVES links.

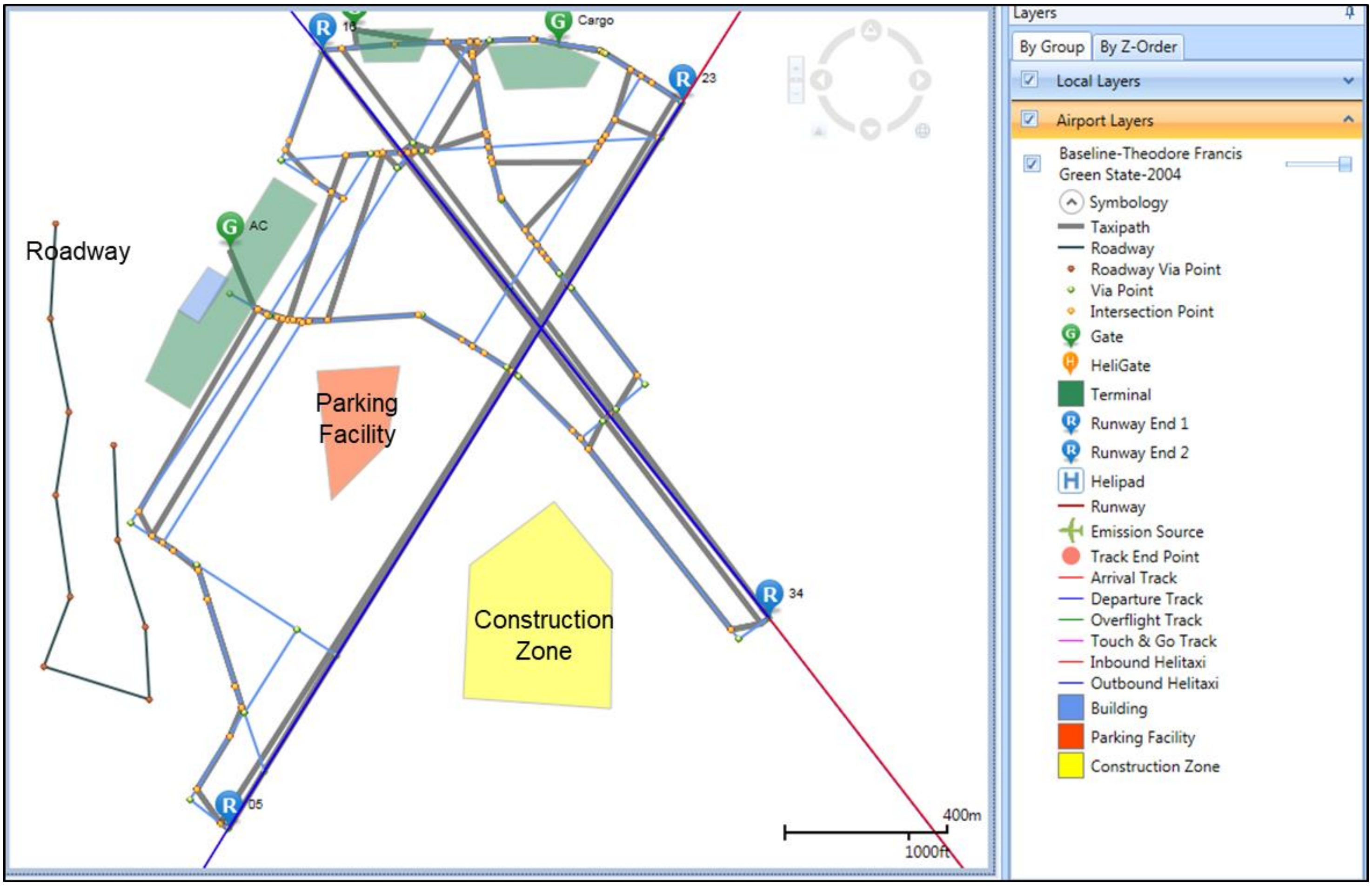


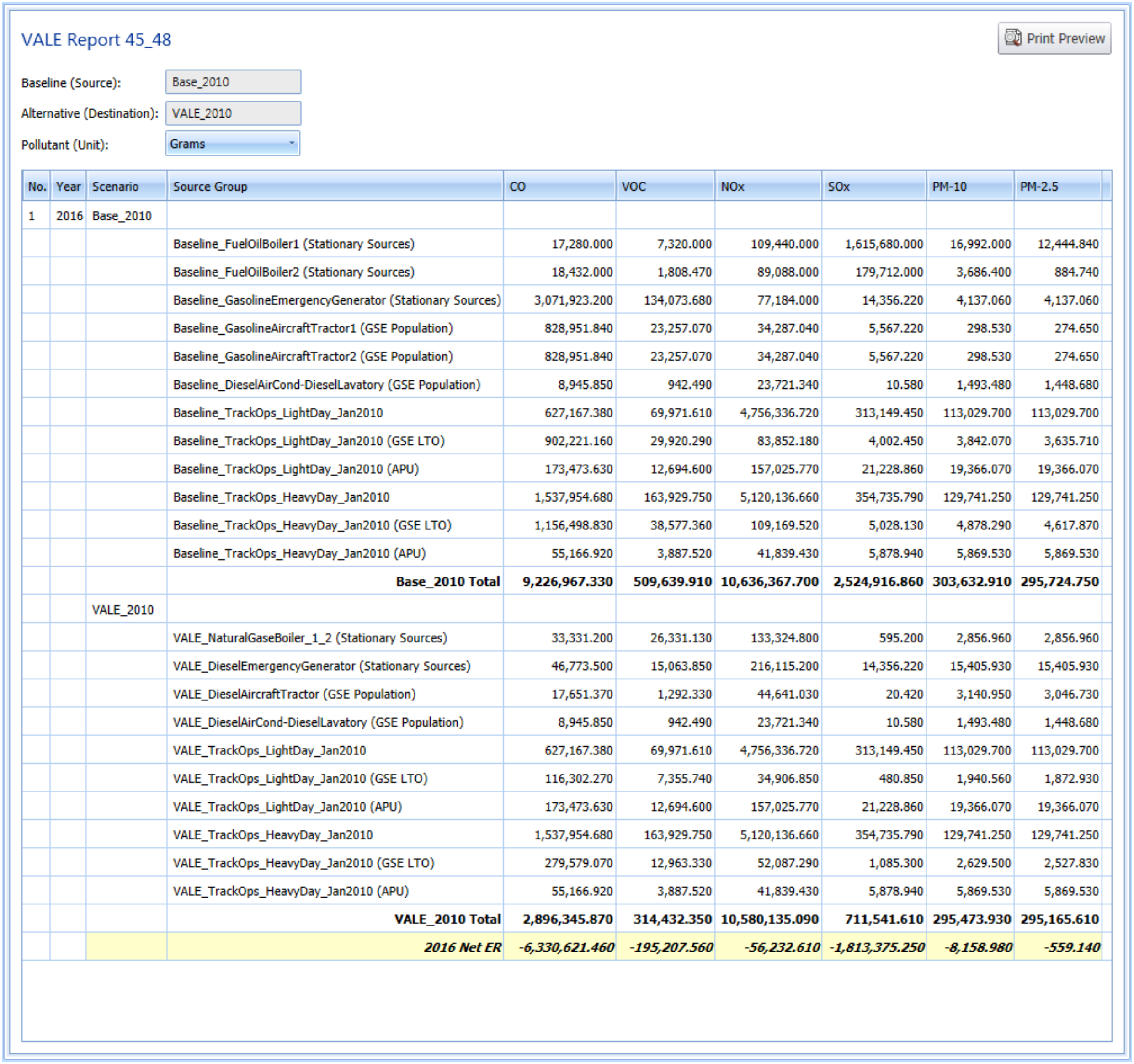
Figure 16: Design Roadway, Parking Facility and Construction Zone in AEDT for MOVES Modeling

VALE Reporting with MOVES

After the roadway, parking facilities, and/or construction operations emissions inventory was calculated externally by the MOVES tool, the emissions inventory results can be imported to AEDT and included in the emissions report for all metric results. To integrate the MOVES inventory scenario with an emissions metric result, one needs to specify the MOVES inventory file in the definitions tab of AEDT. After the MOVES emissions inventory was imported, one can define an emissions metric and select the MOVES inventory scenario in the step of set processing options. Once the metric result is run, one can generate the emissions report which will include the MOVES emissions inventory.

The integration of MOVES emissions inventory was tested with the Voluntary Airport Low Emissions (VALE) report. A VALE reduction report shows net differences in emissions between a baseline and an alternative (VALE) metric result for a single analysis year. The baseline scenario simulates existing conditions while the alternative scenario conveys hypothetical equipment replacements. A test study was used and the VALE report with MOVES emissions inventory was generated. This feature works properly with minor issues which will be fixed. A sample VALE report is shown in Table 21.

Table 21: A Sample VALE Report



VALE Report 45_48

Baseline (Source): Base_2010
Alternative (Destination): VALE_2010
Pollutant (Unit): Grams

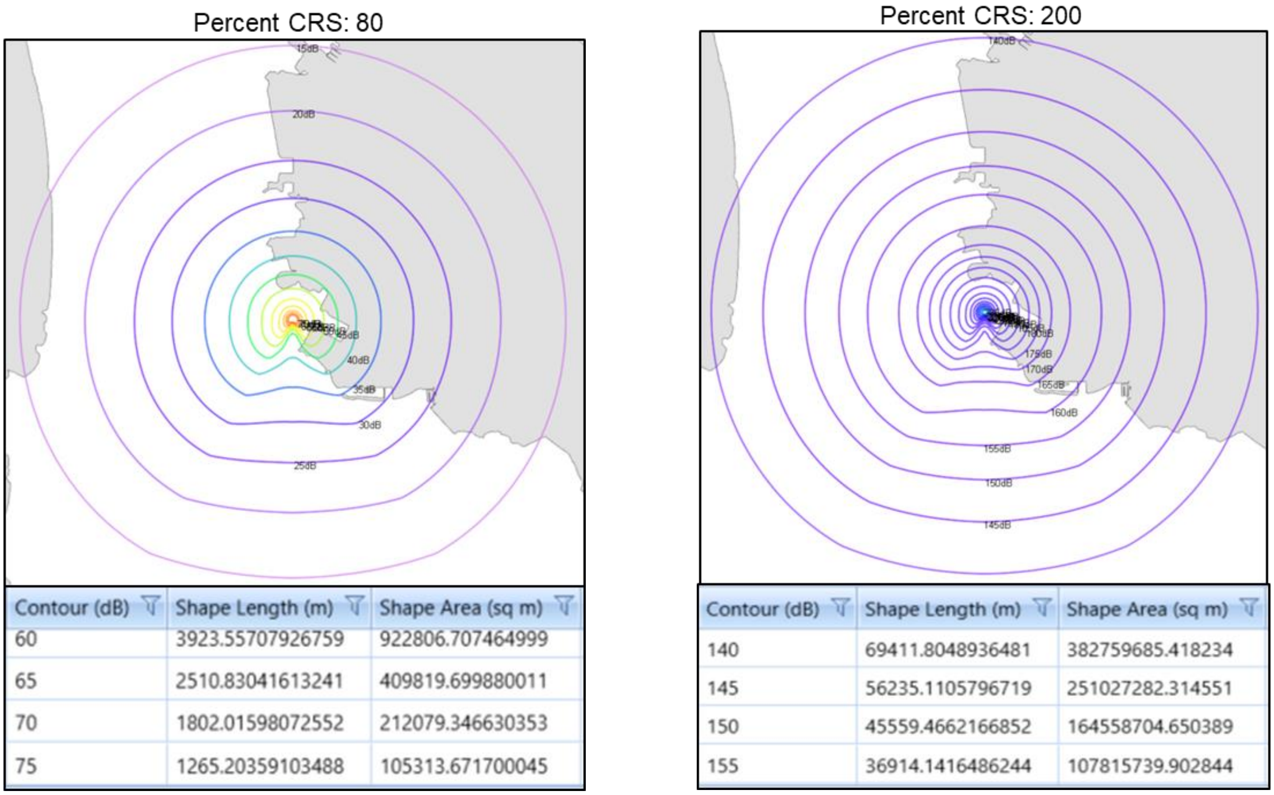
No.	Year	Scenario	Source Group	CO	VOC	NOx	SOx	PM-10	PM-2.5
1	2016	Base_2010							
			Baseline_FuelOilBoiler1 (Stationary Sources)	17,280.000	7,320.000	109,440.000	1,615,680.000	16,992.000	12,444.840
			Baseline_FuelOilBoiler2 (Stationary Sources)	18,432.000	1,808.470	89,088.000	179,712.000	3,686.400	884.740
			Baseline_GasolineEmergencyGenerator (Stationary Sources)	3,071,923.200	134,073.680	77,184.000	14,356.220	4,137.060	4,137.060
			Baseline_GasolineAircraftTractor1 (GSE Population)	828,951.840	23,257.070	34,287.040	5,567.220	298.530	274.650
			Baseline_GasolineAircraftTractor2 (GSE Population)	828,951.840	23,257.070	34,287.040	5,567.220	298.530	274.650
			Baseline_DieselAirCond-DieselLavatory (GSE Population)	8,945.850	942.490	23,721.340	10.580	1,493.480	1,448.680
			Baseline_TrackOps_LightDay_Jan2010	627,167.380	69,971.610	4,756,336.720	313,149.450	113,029.700	113,029.700
			Baseline_TrackOps_LightDay_Jan2010 (GSE LTO)	902,221.160	29,920.290	83,852.180	4,002.450	3,842.070	3,635.710
			Baseline_TrackOps_LightDay_Jan2010 (APU)	173,473.630	12,694.600	157,025.770	21,228.860	19,366.070	19,366.070
			Baseline_TrackOps_HeavyDay_Jan2010	1,537,954.680	163,929.750	5,120,136.660	354,735.790	129,741.250	129,741.250
			Baseline_TrackOps_HeavyDay_Jan2010 (GSE LTO)	1,156,498.830	38,577.360	109,169.520	5,028.130	4,878.290	4,617.870
			Baseline_TrackOps_HeavyDay_Jan2010 (APU)	55,166.920	3,887.520	41,839.430	5,878.940	5,869.530	5,869.530
			Base_2010 Total	**9,226,967.330**	**509,639.910**	**10,636,367.700**	**2,524,916.860**	**303,632.910**	**295,724.750**
		VALE_2010							
			VALE_NaturalGaseBoiler_1_2 (Stationary Sources)	33,331.200	26,331.130	133,324.800	595.200	2,856.960	2,856.960
			VALE_DieselEmergencyGenerator (Stationary Sources)	46,773.500	15,063.850	216,115.200	14,356.220	15,405.930	15,405.930
			VALE_DieselAircraftTractor (GSE Population)	17,651.370	1,292.330	44,641.030	20.420	3,140.950	3,046.730
			VALE_DieselAirCond-DieselLavatory (GSE Population)	8,945.850	942.490	23,721.340	10.580	1,493.480	1,448.680
			VALE_TrackOps_LightDay_Jan2010	627,167.380	69,971.610	4,756,336.720	313,149.450	113,029.700	113,029.700
			VALE_TrackOps_LightDay_Jan2010 (GSE LTO)	116,302.270	7,355.740	34,906.850	480.850	1,940.560	1,872.930
			VALE_TrackOps_LightDay_Jan2010 (APU)	173,473.630	12,694.600	157,025.770	21,228.860	19,366.070	19,366.070
			VALE_TrackOps_HeavyDay_Jan2010	1,537,954.680	163,929.750	5,120,136.660	354,735.790	129,741.250	129,741.250
			VALE_TrackOps_HeavyDay_Jan2010 (GSE LTO)	279,579.070	12,963.330	52,087.290	1,085.300	2,629.500	2,527.830
			VALE_TrackOps_HeavyDay_Jan2010 (APU)	55,166.920	3,887.520	41,839.430	5,878.940	5,869.530	5,869.530
			VALE_2010 Total	**2,896,345.870**	**314,432.350**	**10,580,135.090**	**711,541.610**	**295,473.930**	**295,165.610**
			2016 Net ER	***-6,330,621.460***	***-195,207.560***	***-56,232.610***	***-1,813,375.250***	***-8,158.980***	***-559.140***

Runup Operations for Military Aircraft

Runup operations only generate noise results. In addition, runup operations are only applicable for fixed-wing aircraft and not for helicopters, and they are not associated with tracks. Runup operations for military aircraft was not working properly in AEDT 2b when the AEDT 2b UQ analysis was conducted. The purpose of this task is to test if runup operations for military aircraft are fully supported in AEDT 2c.

To test this function, a runup operation of military aircraft was created. In the process of defining runup operation, one of the key parameters in runup details step needs to be specified. It was found that this parameter can be different for different aircraft, such as power lever angle, percent corrected rotor speed, engine pressure ratio, percent propeller or compressor RPM. The defined runup operation can be edited, copied and deleted.

Several runup operations were created for military aircraft and verified that the function is working properly. The only issue is that, when the runup operation is defined, the key parameter that needs to be specified in runup details can be assigned any value, which can generate infeasible runup operation and noise results. Figure 17 shows that AEDT can generate noise contour for a military aircraft runup operation with the percent corrected rotor speed being 80 and 200. And there is no limit on the percent corrected rotor speed and can go even higher. This generated infeasible noise results, and this issue will be fixed in the future.



Contour (dB)	Shape Length (m)	Shape Area (sq m)
60	3923.55707926759	922806.707464999
65	2510.83041613241	409819.699880011
70	1802.01598072552	212079.346630353
75	1265.20359103488	105313.671700045

Contour (dB)	Shape Length (m)	Shape Area (sq m)
140	69411.8048936481	382759685.418234
145	56235.1105796719	251027282.314551
150	45559.4662166852	164558704.650389
155	36914.1416486244	107815739.902844

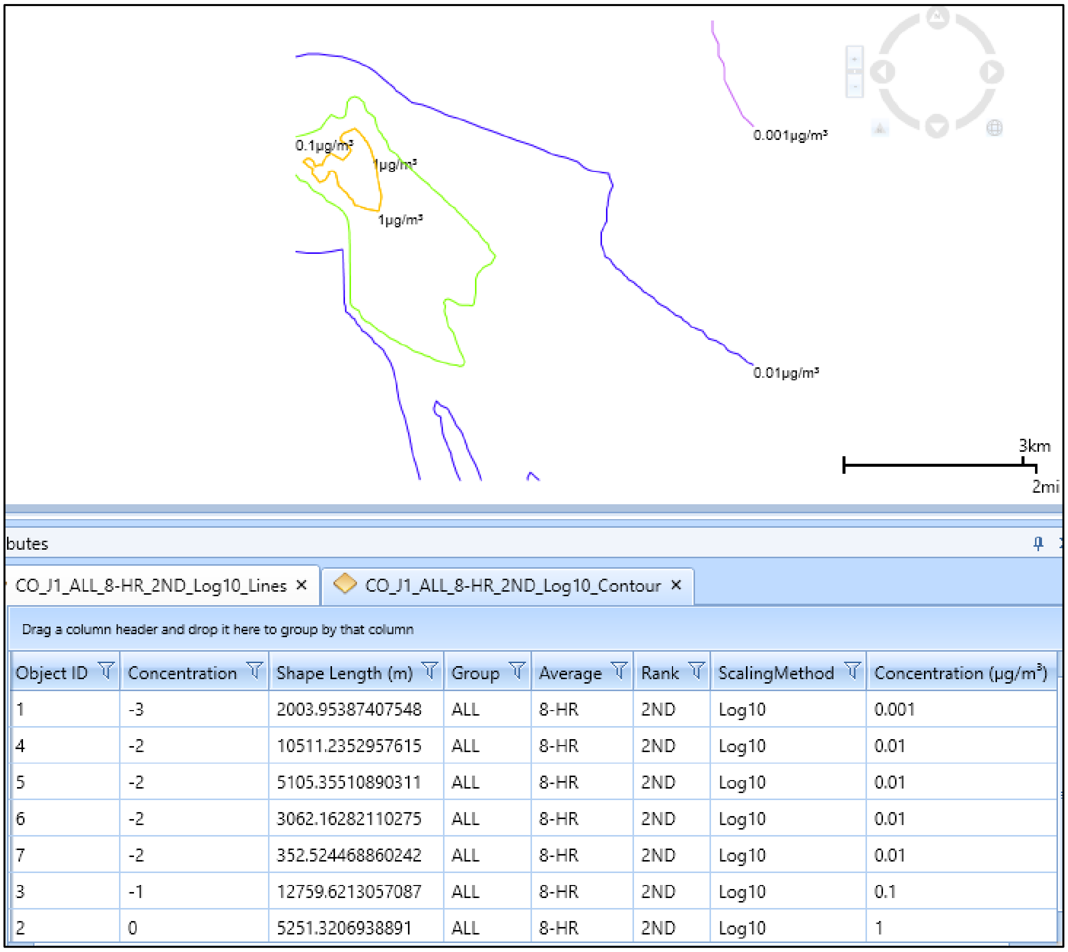
Figure 17: Noise Contours for Runup Operations of Military Aircraft with Different Percent CRS

Emission Dispersion Open Contour

Emission Dispersion Open Contour requires AEDT to be able to generate contour for emission depression analysis. Contour generation requires the grid receptor with a smaller range compared with the noise receptor grid. It is typical to use the spacing for 0.5 nautical mile (926 meter) for noise grid; however, emissions dispersion needs 100 to 200 meter spacing to create a reasonable contour. That is, the emission dispersion contours are generated using grids in meter unit in AEDT. The emission dispersion contours are shown in two scales – linear and log scale in Figure 18.

Emissions can be transported and dispersed over very large distances. Although the focus of most emissions dispersion analyses generated using AEDT will be on receptors close to the airport, there is frequently the need to visualize emission contour lines which are open ended. These open-ended contours could be closed by extending the receptor grid over a very large distance which could be computationally prohibitive. In order for those contours to be accurately represented visually, AEDT was updated to allow for these open-ended contours to be displayed.

To test the emission dispersion open contour function, a study was created and tested. After the study was run, the emission dispersion contours were generated, including open contour lines, as shown in Figure 18. The test showed that AEDT can successfully generate open contours for emission dispersion analysis, and the contours can be displayed in linear or log scales. In addition, AEDT is able to calculate contour area for contours in log scale. One suggestion for this function is that it will be helpful if AEDT can calculate contour area for linear scale as well.



Object ID	Concentration	Shape Length (m)	Group	Average	Rank	ScalingMethod	Concentration (µg/m³)
1	-3	2003.95387407548	ALL	8-HR	2ND	Log10	0.001
4	-2	10511.2352957615	ALL	8-HR	2ND	Log10	0.01
5	-2	5105.35510890311	ALL	8-HR	2ND	Log10	0.01
6	-2	3062.16282110275	ALL	8-HR	2ND	Log10	0.01
7	-2	352.524468860242	ALL	8-HR	2ND	Log10	0.01
3	-1	12759.6213057087	ALL	8-HR	2ND	Log10	0.1
2	0	5251.3206938891	ALL	8-HR	2ND	Log10	1

Figure 18: Emission Dispersion Open Contours

Vector Track

One of the functionalities implemented in AEDT was to input vector track geometry via the GUI by adding a series of track segments. In this capability, the user can select the following types of vector track segments: straight, left turn, and right turn with a proper angle. For a verification purpose, the vector track was created to compare both emission and noise results with a point track and flew one aircraft with the vector track. Once the simulation was completed, both latitude and longitude information were parsed from performance results in order to generate a point track. For example, as can be seen in Figure 19, a single-aisle aircraft was flown from San Diego International Airport and both vector and point tracks were created. In terms of the vector track, the blue line was supposed to be the vector track for departure and it was created by the GUI. On the other hand, the red line referred to the flight for arrival to the airport. Using the results from the vector track, the red dot points were used to create the point track.

Both fuel burn and noise results were compared for the arrival and departure cases between the vector and point track as tabulated below. For fuel consumption comparison, aircraft was flown with both arrival and departure procedures using either vector or point track. As a result, they were almost identical. For noise contour area comparison, 65, 70, and 75 SEL levels were chosen in order to compare the results between vector and point track. As a result, the difference between them was less than one percent.

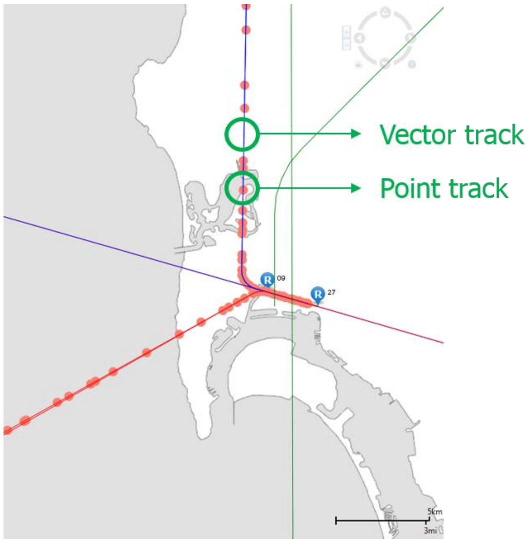


Figure 19. Vector vs. Point Track

Table 22. Fuel burn comparison (Vector vs. Point Track)

	Arrival FB (kg)	Departure FB (kg)
Vector track	281.43	643.24
Point track	281.41	643.77

Table 23. Noise (SEL) comparison (Vector vs. Point track)

SEL Area (km2)	Vector Track	Point Track	Difference (%)
65	269.17	271.25	0.8
70	169.96	170.94	0.6
75	92.27	92.56	0.3

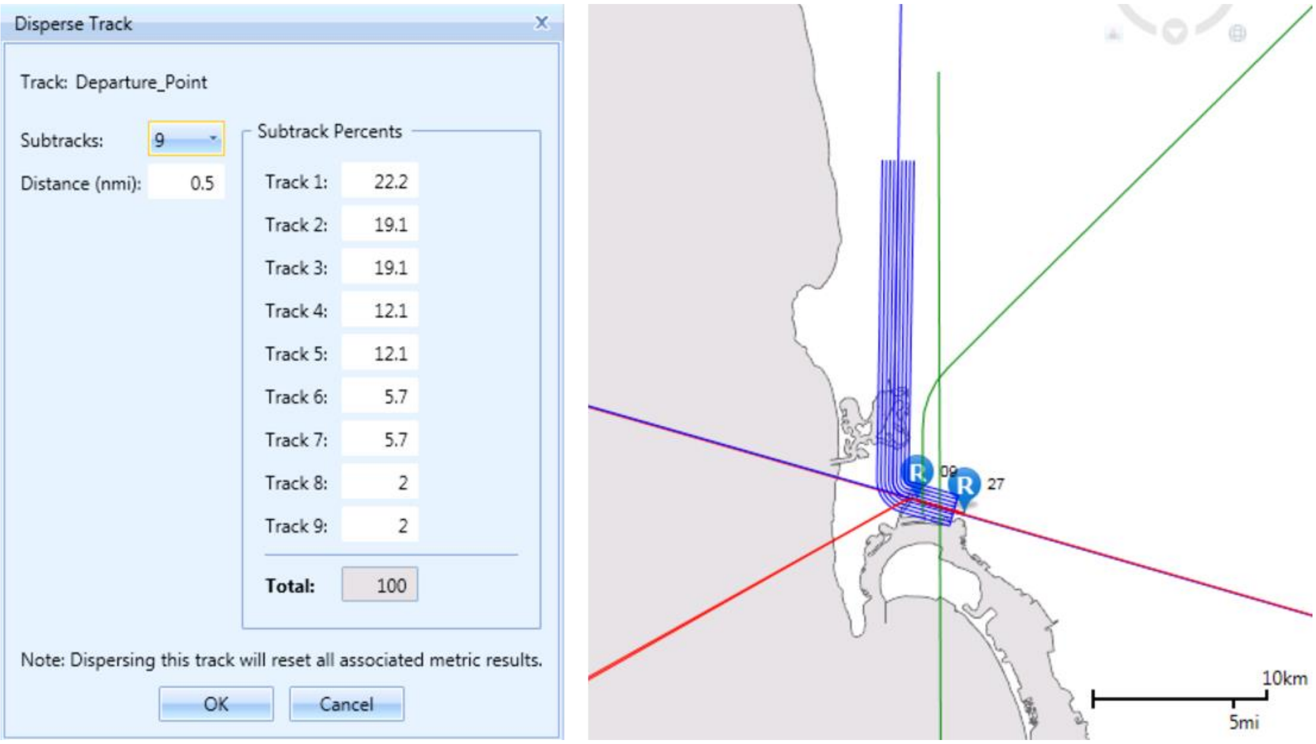
Track Dispersion

One of the key features added to AEDT is the capability of track dispersion. Users have the ability to edit or modify an existing ground track with dispersion through the AEDT GUI environment. Since the track dispersion is designed only for a point track at this point, GT created a point track and made dispersion with the track. For a verification purpose, a case study was defined with nine dispersion sub-tracks and one hundred operations as shown in Figure 20.

In Figure 20, one departure point track was at first defined at San Diego International Airport. And then, the blue line, which was a point track for departure operation, was dispersed with the capability. With the dispersion, eight sub-tracks were generated with different distances. All blue lines shown in Figure 20 represent the dispersed tracks.

In order to see the dispersion effect, DNL contour area was compared between dispersed and undispersed tracks. As a result, the difference of DNL areas between dispersed and undispersed track was increased as the DNL level was increased.

It does make sense because dispersed track would be having more impacts on the noise area than undispersed track. The DNL results are tabulated in Table 24, which shows from 50 to 80 DNL levels.


Disperse Track

Track: Departure_Point

Subtracks: 9

Distance (nmi): 0.5

Subtrack Percents

Track 1: 22.2
Track 2: 19.1
Track 3: 19.1
Track 4: 12.1
Track 5: 12.1
Track 6: 5.7
Track 7: 5.7
Track 8: 2
Track 9: 2

Total: 100

Note: Dispersing this track will reset all associated metric results.

Figure 20: Case study setup for dispersion test

Table 24: DNL comparison (Dispersed vs. Undispersed track)

DNL Area (km^2)	Dispersed track	Undispersed track	Difference (%)
50	183.51	181.95	0.9
60	41.70	40.57	2.8
70	8.58	6.51	31.8
80	1.30	0.89	46.1

Contour Combination

One of the capabilities implemented in AEDT is to enable users to import grids from other noise models and to combine grids. In terms of contour combination, users are even able to combine more than two grids. For a verification purpose, the capability was tested with two cases: 1) Using the grid from other noise model and 2) Using multiple grids created by GT in AEDT. First, two different grids were successfully imported to AEDT and combined with each other. Second, the capability was tested by creating a new study which included three different grid spacing in AEDT as shown in Figure 21.

In Figure 21, three different grid types were created with different grid spacing. For example, the first grid so-called as coarse grid was created with 1.0 nautical mile grid spacing. The second grid so-called as medium grid was created with 0.5 grid spacing. For this reason, an area of the medium grid is less than the one of coarse grid. Finally, the fine grid with grid spacing 0.25 was created. As expected, it was successfully merged which is shown in the bottom of Figure 21. Also, the results were successfully obtained from the combined grid as expected.

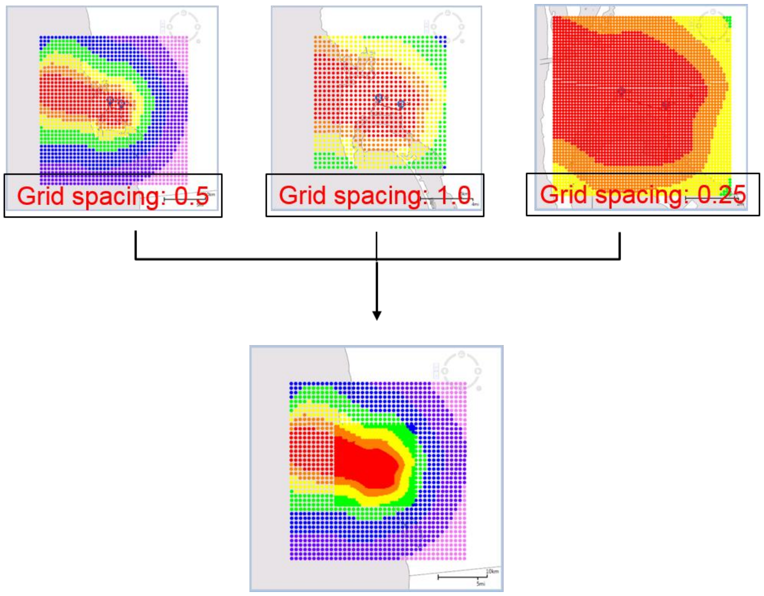


Figure 21: Three different grids with consistency

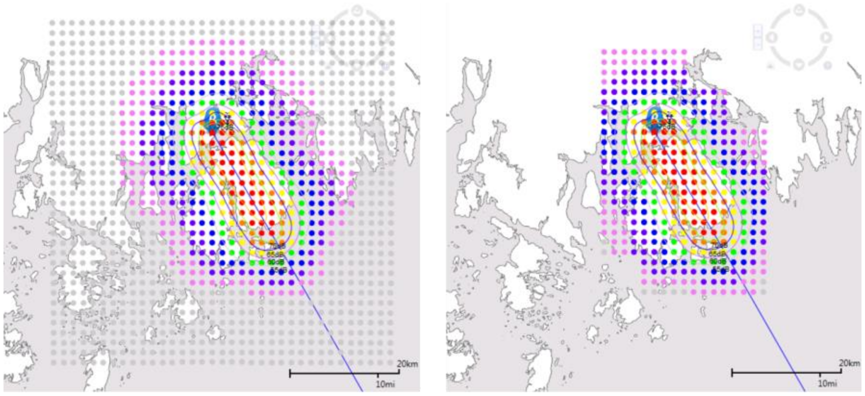
Dynamic Grid

In AEDT, noise contours are usually calculated from a grid receptor with equally spaced contour grid, namely fixed grid. Dynamic grid, which is variably spaced contour grid, was implemented as one of capabilities in AEDT. The dynamic grid method would start with small grids and expand outward until the desired contour level is closed. To be more specific, noise levels are first computed for the starting receptor grid and are compared to the specified expansion level. If any noise level exceeds the minimum expansion level, the grid expands in that direction by adding a new grid. This is done for all four sides of the starting grid and the process continues until no noise levels on the edges of the grids exceed the expansion level and the contour is closed.

In order for a verification purpose, two studies were created to evaluate the functionality of dynamic grid for both dB and non-dB metrics. In terms of the test for dB metric, the SEL metric was chosen and defined 55dB as the minimum expansion level for the dynamic grid test. As a result, the noise contour between fixed and dynamic grids was almost identical.

In Figure 22, the fixed grids described in the left hand side were defined around KBHB airport and a single-aisle aircraft was flown to south-east direction. As expected, the fixed grids were all used to compute noise levels. On the other hand, when dynamic grid was turned on from the option, it seemed that AEDT calculated grids less than the fixed grids. In the meantime, the noise contours for both fixed and dynamic grids were almost identical.

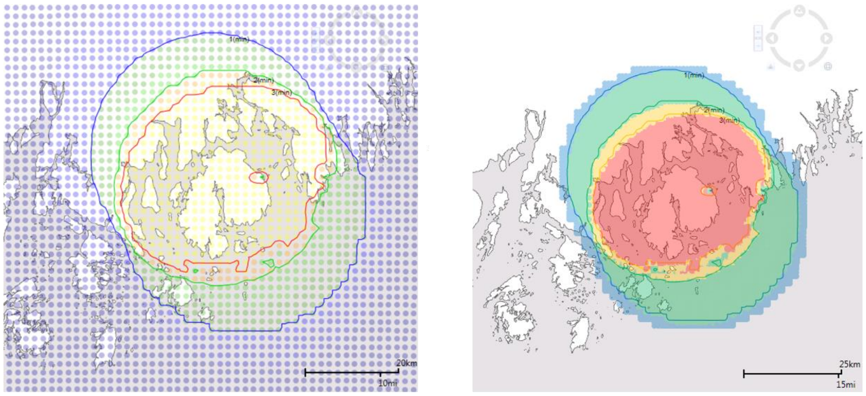
In terms of the test for non-dB metric, TAUD was selected as a non-dB metric and defined one minute as the minimum expansion level. Although the dynamic grid worked well for TAUD, it was found that there was an error for generating contour area with respect to the TAUD metric. However, the issue had been resolved since it was reported to the development team and was retested it again to make sure that the contouring algorithm works well. Finally, it was found that it worked successfully without any contour algorithm problems.



Fixed Grid Dynamic Grid

Figure 22: Fixed vs. Dynamic grid (SEL)

In Figure 23, the dynamic grids used less grid points than a fixed grid. Although the dynamic grid method used less grid points, the contour areas generated by the dynamic grid were almost identical compared to the fixed grid. For each colored line, it represented the level of contour areas.



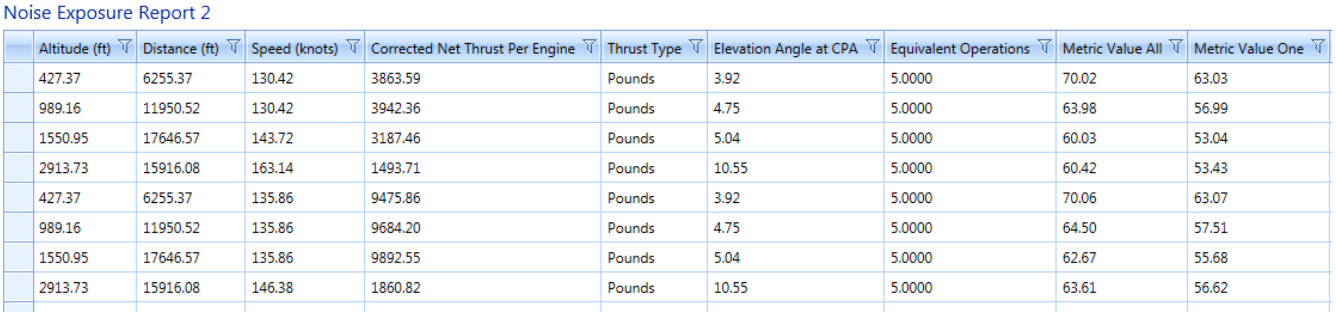
Fixed Grid Dynamic Grid

Figure 23: Fixed vs. Dynamic grid (TAUD)

Detailed Noise

INM had a capability to store noise results from a flight segment of each of the flights when detailed grid option was used. For AEDT, a capability to set up and view the detailed noise report through the GUI was implemented. Therefore, users were able to obtain the detailed noise results from each grid point as well as every combination of aircraft, profile, and track.

Three different cases were tested to evaluate the functionality of detailed noise implemented in AEDT. The test case one was supposed to be single arrival flight with standard option. The option was chosen to compare it with the test case two which was also supposed to be a single arrival flight but with detailed noise option. Lastly, the test case three was defined to verify if the detailed noise functionality was also working with multi-flights. From all the tests defined, the detailed noise functionality worked well as intended.



Noise Exposure Report 2

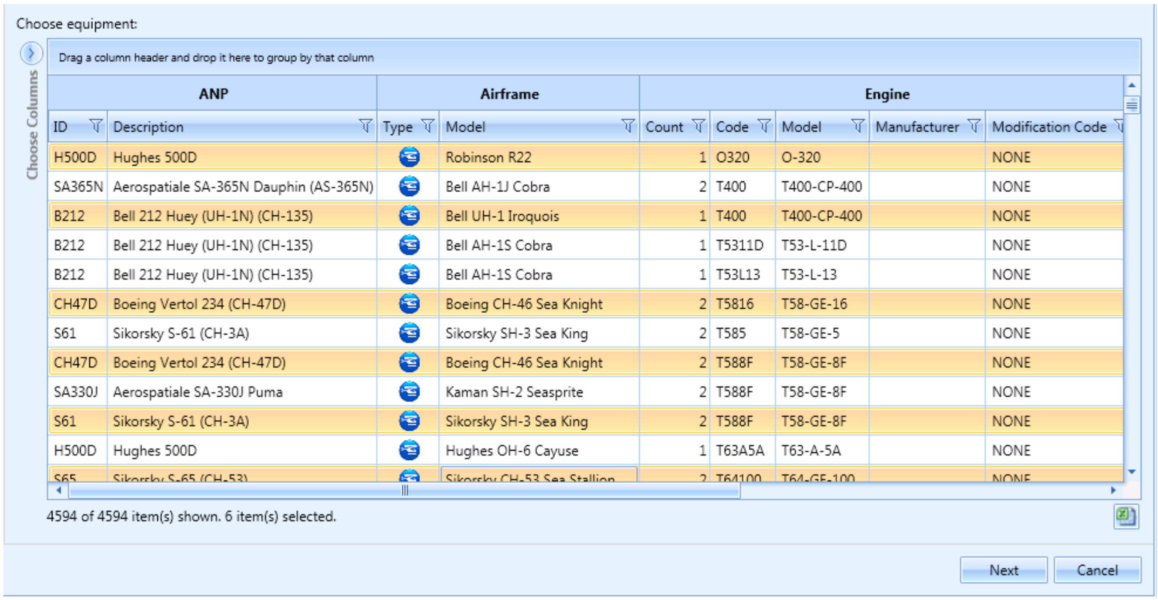
Altitude (ft)	Distance (ft)	Speed (knots)	Corrected Net Thrust Per Engine	Thrust Type	Elevation Angle at CPA	Equivalent Operations	Metric Value All	Metric Value One
427.37	6255.37	130.42	3863.59	Pounds	3.92	5.0000	70.02	63.03
989.16	11950.52	130.42	3942.36	Pounds	4.75	5.0000	63.98	56.99
1550.95	17646.57	143.72	3187.46	Pounds	5.04	5.0000	60.03	53.04
2913.73	15916.08	163.14	1493.71	Pounds	10.55	5.0000	60.42	53.43
427.37	6255.37	135.86	9475.86	Pounds	3.92	5.0000	70.06	63.07
989.16	11950.52	135.86	9684.20	Pounds	4.75	5.0000	64.50	57.51
1550.95	17646.57	135.86	9892.55	Pounds	5.04	5.0000	62.67	55.68
2913.73	15916.08	146.38	1860.82	Pounds	10.55	5.0000	63.61	56.62

Figure 24: Detailed noise example generated in AEDT

In Figure 24, the table was created in AEDT by choosing the detailed noise option. The table included a lot of information such as noise level, speed, distance, and elevation angle at Closed-Point-Approach (CPA). To manage the data size, the results were stored for a Closed-Point-of-Approach (CPA), which is the closest point to the receptor, to the receptors and were compared under the same conditions. From the comparison, the thrust values from AEDT were about 3.45 times greater than those of INM in Sprint 82. This was because there was a bug in terms of calculating equivalent operations. However, in Sprint 88, the difference between INM and AEDT with respect to the thrust values was only 0.4%.

Bulk Operation Creation

One of the most enhanced functionalities in AEDT was to implement bulk operation. In the bulk operation, the user could choose multiple equipment at the same time. In addition, the user could specify stage length for each equipment and choose multiple flight tracks. For example, if users selected three different aircraft and two flight tracks, then AEDT would provide users to six combinations of aircraft operations. Six different aircraft were selected at the same time in the operation tab, as depicted in Figure 25 to test this functionality. However, a few minor issues were found that users could not delete multiple operations at the same time. Although the user could choose multiple operations, the operations could not be deleted simultaneously. In addition, there was another minor issue that a user could not select multiple equipment when the filter option was used to find out different equipment in a sequence. These minor issues are investigated under development team members.



Choose equipment:

Drag a column header and drop it here to group by that column

ANP		Airframe		Engine				
ID	Description	Type	Model	Count	Code	Model	Manufacturer	Modification Code
H500D	Hughes 500D		Robinson R22	1	O320	O-320		NONE
SA365N	Aerospatiale SA-365N Dauphin (AS-365N)		Bell AH-1J Cobra	2	T400	T400-CP-400		NONE
B212	Bell 212 Huey (UH-1N) (CH-135)		Bell UH-1 Iroquois	1	T400	T400-CP-400		NONE
B212	Bell 212 Huey (UH-1N) (CH-135)		Bell AH-1S Cobra	1	T5311D	T53-L-11D		NONE
B212	Bell 212 Huey (UH-1N) (CH-135)		Bell AH-1S Cobra	1	T53L13	T53-L-13		NONE
CH47D	Boeing Vertol 234 (CH-47D)		Boeing CH-46 Sea Knight	2	T5816	T58-GE-16		NONE
S61	Sikorsky S-61 (CH-3A)		Sikorsky SH-3 Sea King	2	T585	T58-GE-5		NONE
CH47D	Boeing Vertol 234 (CH-47D)		Boeing CH-46 Sea Knight	2	T588F	T58-GE-8F		NONE
SA330J	Aerospatiale SA-330J Puma		Kaman SH-2 Seasprite	2	T588F	T58-GE-8F		NONE
S61	Sikorsky S-61 (CH-3A)		Sikorsky SH-3 Sea King	2	T588F	T58-GE-8F		NONE
H500D	Hughes 500D		Hughes OH-6 Cayuse	1	T63A5A	T63-A-5A		NONE
S65	Sikorsky S-65 (CH-53)		Sikorsky CH-53 Sea Stallion	2	T64100	T64-GE-100		NONE

4594 of 4594 item(s) shown. 6 item(s) selected.

Figure 25: Bulk operation example

Milestone(s)

Milestone	Due Date	Estimated Date of Completion	Actual Completion Date	Status	Comments (Problems & Brief Resolution Plan)
A36 Kickoff Meeting	5/3/2016	5/3/2016	5/3/2016	Completed	
Quarterly Report (Aug)	7/31/2016	7/31/2016	7/31/2016	Completed	
ASCENT Meeting	9/27-28/2016	9/27-28/2016	9/27-28/2016	Completed	
Quarterly Report (Nov)	10/31/2016	10/31/2016	10/31/2016	Completed	
Annual Report	1/18/2017	1/18/2017	1/13/2017	Completed	
Quarterly Report (Jan)	1/31/2017	1/31/2017	1.27/2017	Completed	
Quarterly Report (March)	3/31/2017	3/31/2017	3/31/2017	Completed	
ASCENT Meeting	4/18/2017	4/18/2017	4/18/2017	Completed	
Quarterly Report (June)	6/30/2017	6/30/2017	6/30/2017	Completed	
ASCENT Meeting	9/26/2017	9/26/2017	9/26/2017	Completed	
Quarterly Report (Oct)	10/30/2017	10/30/2017	10/30/2017	Completed	
Annual Report	11/30/2017	11/30/2017	11/30/2017	In Progress	

Major Accomplishments

Starting from January 2017, all the new AEDT sprint releases including Sprints from 80 to 94 have been tested. Sprints 80 – 94 included two public releases of AEDTs, namely AEDT 2c SP2, and AEDT 2d.. Fifteen versions of AEDT have been tested focusing on new features and capabilities added. Some of the new features/capabilities were minor updates to the GUI, bug fixes, or data updates. Major updates included enhanced nvPM, VALE reporting with MOVES, runup operation of military aircraft, open contour, vector track, track dispersion, contour combination, dynamic grid, detailed noise and bulk operation creation. In order to understand the background of new AEDT features, all the relevant documents were reviewed including the software requirement documents, Database Design Document, AEDT sprint release notes, updated technical manual, user manual, and research papers/reports. Basic testing of all the new AEDT versions and service packs was completed to confirm its functionality and a number of minor and major bugs and reported them to the FAA and the development team via bi-weekly ASCENT project telecons and weekly AEDT development-leads calls. Through the on-line system named Team Foundation Server (TFS), identified issues and follow-up actions taken by the developers were documented and shared. The TFS also allows for reporting any potential areas of improvements in AEDT algorithms and user-friendliness.

Finally, further analysis was conducted to investigate the differences in noise, fuel consumption, emission inventory and emission dispersion between AEDT and the legacy tools reported in the original AEDT 2b report. Studies were performed for Use Case B&C, Use Case D, and Use Case E to investigate the differences in emissions and noise between AEDT, EDMS and INM. The investigations of the differences between AEDT and the legacy tools focuses on evaluating the assumptions, methods, and implementation for noise and emissions calculations. Thus, technical manual of AEDT and legacy tools were reviewed to understand the assumptions and methods used by different tools, and the factors that have impact on the noise and emissions calculation were identified. Additional studies were designed and performed to further validate the metric results, and findings and recommendations were reported.

Publications

Yongchang Li, Don Lim, Michelle Kirby, Dimitri Mavris, George Noel, Uncertainty Quantification Analysis of the Aviation Environmental Design Tool in Emission Inventory and Air Quality Modeling, Submitted to AVIATION 2018 conference.

Dongwook, Lim, Yongchang Li, Matthew J Levine, Michelle R Kirby, Dimitri, Mavris, Parametric Uncertainty Quantification of Aviation Environmental Design Tool, Submitted to AVIATION 2018 conference.

Junghyun Kim, Dongwook Lim, Yongchang Yi, Michelle Kirby, and Dimitri Mavris, Parametric Study of Noise Impact on the Airspace over the Acadia National Park using Time-Audible metric in AEDT, Submitted to AVIATION 2018 conference.

Outreach Efforts

None

Awards

None

Student Involvement

Junghyun (Andy) Kim is a third year PhD student who started in fall 2015. Mr. Kim has conducted a literature review on UQ methods, and performed tests for newly release AEDT features. Mr. Kim is being trained on related tools such as INM, AEDT Tester, AEDT2c and AEDT 2d.

Ameya Behere is a second year PhD student who started in fall 2016. Mr. Behere has conducted a literature review on UQ methods, and performed tests for newly release AEDT features. Mr. Behere is being trained on related tools such as INM, AEDT Tester, AEDT2c and AEDT 2d.

Evanthia (Eva) Kallou is a third year PhD student who started in fall 2015. As a Graduate Research Assistance, Ms. Kallou has conducted a literature review on UQ methods. Ms. Kallou is being trained on related tools such as EDMS, AEDT Tester, AEDT2c and AEDT 2d.

Plans for Next Period

GT will continue uncertainty quantification tasks for new AEDT 2d releases. AEDT 2e is planned to be released in mid-March 2018. GT will perform the validation and verification tasks for the preliminary versions of AEDT 2d to identify any issues that need to be addressed by the development team.

Task 1. Proper Definition of AEDT Input Parameter Uncertainty

The first step in the UQ effort is to properly define the problem. For each of the AEDT service pack releases, GT will define the scope of the UQ effort identifying the key changes to the AEDT versions from the previous releases. Depending on the type of updates incorporated, it would be required to identify the key sources of uncertainties and properly define the uncertainties for the input parameters if it is necessary.

Task 2. Verification and Validation plus Capability Demonstrations

GT will continue to conduct V&V and capability demonstrations of the newly released AEDT versions. The V&V analysis can take a couple of different approaches depending on the type of updates and data availability. In the past UQ efforts, one of the most important methods of ensuring confidence in the tool capability was to conduct a use case(s) using both legacy tools and the new AEDT release and compare the results. This method would be the most appropriate way whenever a legacy tool has the same or similar functionalities and a validated use case has been modeled in that legacy tool. When the new functionality of AEDT does not exist in the legacy tools, the V&V exercise should use direct comparisons to the results generated by the mathematical algorithms behind the newly added functionality and/or real world data whichever available.

Task 3. Identification of Important Output to Input Relationships (Optional)

This optional task may not be performed for every AEDT service pack releases. Instead, this task will be performed when a major feature is added to the AEDT, and if potential sources of uncertainties remain through the analysis of previous two tasks. The outcome of this task will be the identification of the key input drivers across multiple vehicle types to multiple

AEDT metric outputs. This can provide a comprehensive insight to the uncertainty associated with AEDT outputs and the joint-distribution of Fleet DB coefficients. Various uncertainty quantification techniques will be used depending on the metric of interest. This may include, but not limited to the following techniques: Analysis of Variance (ANOVA), Multivariate Analysis of Variance (MANOVA), Monte Carlo Simulation, Copula Techniques, or Global Sensitivity Analysis. The specific techniques will be proposed by GT and reviewed by the FAA for concurrence.[i]

Task 4. Guidelines for Future Tool Research

In this task, each of the prior tasks will culminate into a summary document of the data assumptions, techniques utilized, the resulting observations and findings to help guide the FAA to further research the areas of AEDT development to improve its supporting data structure and algorithms. In addition, the document will build confidence in AEDT's capability and fidelity and help users to understand the sensitivities of output response to the variation of input parameters/assumptions.

References

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[2] US FAA, AEDT 2a SP2 UQ Supplemental Report, 2014

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[15] EUROCONTROL, Base of Aircraft Data (BADA) Aircraft Performance Modeling Report, EEC Technical/Scientific Report No. 2009-009, March 2009
