Project 036 Parametric Uncertainty Assessment for AEDT 2b

Georgia Institute of Technology

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- FAA Award Number: 13-C-AJFE-GIT, Amendment 019 and Amendment 029
- Period of Performance: May 1, 2016 – April 30, 2017
- Task(s):
    1. Proper Definition of AEDT Input Parameter Uncertainty
    2. Verification and Validation plus Capability Demonstrations
    3. Identification of Important Output to Input Relationships (Optional)
    4. Guidelines for Future Tool Research
- Augmented Task(s):
    1. Use Case A – Inventory Analysis
    2. Use Case B and C– NEPA/CAA Analysis
    3. Use Case D – Part 150 Analysis
    4. Use Case E – Part 1: Air Traffic Airspace and Procedure Analysis

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.

Investigation Team

Prof. Dimitri Mavris, Dr. Michelle Kirby, Dr. Dongwook Lim, Dr. Yongchang Li, Dr. Matthew Levine, Evanthia Kallou (Graduate student), Junghyun Kim (Graduate student), with consultation/support by research staff Dr. Holger Pfaender.

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 has been released in two phases. The first version, AEDT 2a, was released in March 2012 [US FAA, 2014]. The second version of AEDT 2b was released in May 2015. AEDT is scheduled to be updated three times in the next 12 months, and ultimately a full new version should be available in the next three to five years.

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 Design Test Cases to Test the Functionalities and Capabilities of AEDT

Objective(s)

The first step in the UQ effort is to properly define the problem. For each of the AEDT 2b and 2c service pack releases, GT defined 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 necessary to identify the key sources of uncertainties and the best approach to conduct V&V and parametric uncertainty analysis in Task 2 and Task 3. Depending on the analysis scope of the V&V, Task 3 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 GT team remains flexible in the choice of the V&V approach and the work scope. GT will use the best available methods and data in order to ensure accuracy and functionalities of future AEDT versions based on the discussion with the FAA/AEE.

Research Approach

FAA/AEE's AEDT has been the official environmental consequence modeling tool for US and ICAO CAEP for many years. 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 1, 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 (Table 1). 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.

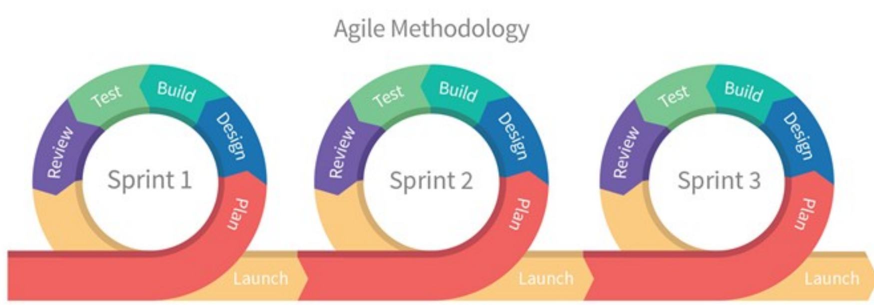

Figure 1: The Agile Methodology [Source: http://www.screenmedia.co.uk]

Table 1: 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
4/30/2017	Project End

For each of the AEDT sprint releases, GT reviewed the AEDT requirement documents and AEDT release notes to identify the key additional features and functionalities that need to be tested. During the period of research period of May 2016 and December 2016, ten versions of AEDT were released including three public releases of AEDT 2b SP3, AEDT 2c, and AEDT 2c SP1, as listed in Table 1.

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

- Thrust type other (TTO) aircraft emissions
- VALE report
- EDMS2ASIF converter and EDMS to AEDT Importer
- Background emission concentration
- Improved nvPM methods
- Environmental Justice (EJ)
- Time audible (TAUD) noise metrics
- Number Above (NA) noise metrics

GT has either completed or in the process of performing V&V and capability demonstration of the new features listed above. The details on the V&V process are discussed in Task 2.

Task 2 Verification and Validation plus Capability Demonstrations

Objective(s)

In Task 2, GT conducted V&V and capability demonstrations 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

Starting from May 2016, GT has tested all the new AEDT versions released including Sprints from 70 to 79. Sprints 70 – 79 included three public versions of AEDT, namely AEDT 2b SP3, AEDT 2c, and AEDT 2c SP1. GT tested the ten versions of AEDT 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 improved VALE reporting capability, implementation of TTO aircraft fuel burn and emission calculations, implementation of Environmental Justice capability, the addition of TAUD and NA noise metrics, improved nvPM calculations, the addition of background emission concentration, and new features on emission dispersion display.

In order to understand the background of new AEDT features, GT reviewed the relevant documents including the software requirement documents, Database Design Documents (DDD), AEDT sprint release notes, updated technical manual [US FAA, 2012, 2016], user manual [US FAA, 2014,2016], and research papers/reports [Noel, 2010 and 2011; Willcox, 2010; Allaire and Willcox, 2010; EUROCONTROL, 2009]. GT has conducted basic testing of all the new AEDT versions to confirm its functionality. While some of the tests are in progress, the next subsections discuss the current progress and findings in more details.

Thrust Type Other Aircraft Fuel Burn and Emissions

In Sprint 67 of AEDT 2b, the Boeing Fuel Flow Method 2 (BFFM2) for estimating aircraft emissions was applied to ANP airplanes that are designated as having a thrust setting type that is recognized as 'other' by the AEDT 2b Aircraft Performance Module (APM). All thrust type settings besides pounds thrust (THRUST_SET_TYPE = B) are recognized as 'other' by the APM and, prior to Sprint 67, produced a 0 value for all emissions results when flown in AEDT 2b. The ANP airplanes affected by the application of the BFFM2 in sprint 67 map to 192 airframe and engine combinations in the FLEET database, 134 of which can be mapped to EDMS aircraft by airframe model and engine model. For convenience, these aircraft are referred to as Thrust Type Other (TTO) aircraft. This task was focusing on testing if AEDT 2b can produce emission results for TTO aircraft using BFFM2 and validating the emission results against EDMS emission results.

GT obtained the EDMS study 'STUDY_DULLES_TTO' containing a single departure and arrival for each of the TTO aircraft as well as single departure and arrival helicopter operations at Washington Dulles International Airport. In addition, GT obtained the EDMS 5.1.4 program for running the EDMS study. The EDMS study was first exported as a text file and then was used along with the schedule file to create an AEDT 2b study using the EDMS2ASIF converter. It was found that the AEDT study created does not have taxi time specified. The AEDT study was modified to contain taxi time in mode durations matching those of EDMS taxi operations. In addition, it was found that the weather (specifically, temperature) was different for the DULLES airport between AEDT and EDMS. Thus, the temperature in AEDT was modified to match the temperature in EDMS. Then both the AEDT and EDMS studies were run. Table 2 shows the comparison of fuel burn and emission results.

Table 2: Fuel Burn and Emission Comparison between AEDT and EDMS

	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	278449.01	9787.76	5909.34	6828.59	6789.81	6826.16	2334.55	878506.61	326.12	76.72	76.72
EDMS	293437.803	10322.885	6213.019	7180.958	7141.346	7179.288	2531.641	925796.212	379.112	319.815	319.815
Diff	-5.11%	-5.18%	-4.89%	-4.91%	-4.92%	-4.92%	-7.79%	-5.11%	-13.98%	-76.01%	-76.01%

Table 2 shows that AEDT underestimates fuel consumption and emissions from the TTO aircraft compared to EDMS. The difference in fuel consumption between AEDT and EDMS is about -5.11%. The difference for the most of other pollutants is under -5%, which is very close to the fuel burn difference. The -7.79% difference for NO_x and -13.98% for SO_x are reasonably close to the fuel consumption difference. One exception is the differences in PM, which is over -76%. To validate the fuel consumption and emission results, GT fully investigated the result differences between AEDT and EDMS by comparing:

- ANP DB coefficients for the TTO aircraft
- Engine DB coefficients for the TTO aircraft
- Fuel burn and emission calculation algorithm (APM and AEM Modules)

The main difference in fuel burn comes from the use of a different version of emission databank (EDB). AEDT (Sprint 78) uses ICAO EDB Issue 22, released on February 5, 2016, while EDMS 5.1.4 uses ICAO EDB Issue 19, issued on April 15, 2013. GT checked the two versions of the EDB and found differences in fuel flow indices and emission indices for many of the TTO aircraft. This explained the differences in fuel burn and emissions including CO, HC, TOG, VOC, NMHC, NOx, CO2 and SOx, except for PM.

For PM calculation, GT investigated the EDMS and AEDT technical manuals and found that AEDT uses FOA 3 adopted by ICAO CAEP while EDMS uses FOA 3a (for US airport), which is a more conservative method modified by the US EPA [CSSI, 2013 and 2014; US FAA, 2016]. FOA 3.0 and 3.0a account for the formation of volatile PM components from fuel sulfur content (FSC) and hydrocarbon (fuel) organics, each component with its own modeling assumptions [Wayson, et.al, 2009; Peck et.al, 2012 and 2013]. FOA 3.0a adds additional computations to account for volatile organic-driven PM from the loss of lubrication oil, for only the takeoff and climb out modes. The contributing modeled species to the volatile PM component are volatile sulfates, fuel organics, and in the case of FOA 3.0a only, lubrication oil. For each of contributing species, an Emission Index (EI) value is calculated, and all EI values are summed to provide a complete estimation for the volatile PM EI.

Table 3 lists the sulfur factors used by FOA 3 and FOA 3a methods for calculating sulfur PM EI. The table shows that FOA 3a has over twice the sulfur to sulfate conversion rate (ε) than the FOA 3 method has. Table 4 lists the assumptions used to calculate organic PM EIs. As can be seen, the PM EI for volatile organic for FOA 3a is almost 5 times as the one of FOA 3.

Table 3: Sulfur Factors for FOA 3 and FOA 3a Methods

Fuel Chr	FOA3	FOA3a
FSC (g / g)	0.00068	0.00068
ε (%)	0.024	0.05
Ma	96	98

Table 4: Assumption of FOA 3 and FOA 3a for Organic PM EI Calculation

LTO Mode	FOA3 $EI_{PMVol\text{-}orgCFM56}$ (mg/kg fuel) APEX1	FOA3a $EI_{PMVol\text{-}orgCFM56}$ (mg/kg fuel) APEX1	$EI_{HCCFM56}$ (g/kg fuel) ICAO Databank
Takeoff	4.6	(1.2 + 19)	0.04
Climb-out	3.8	(2.9 + 16)	0.05
Approach	4.5	(4.5 + 10)	0.08
Idle	11.3	(11.3 + 25)	1.83

Since the FSC and sulfur to sulfate conversion rate can be customer defined in AEDT, GT then modified these sulfur factors to match the ones in EDMS. After the modification, equivalently AEDT is also using FOA 3a method to calculate the sulfate PM (PMSO). Table 5 shows the PM comparison between AEDT and EDMS before (SFs1) and after (SFs2) matching the sulfur factors. It can be seen that the difference between AEDT and EDMS in PMSO reduced to -5.27% from -60.72%. This -5.27% difference after matching the sulfur factors is mainly attributed to the fuel burn difference of -5.11% as shown in Table 2. Table 5 also shows that EDMS produces about 5 times of organic PM (PMFO) than AEDT does. This is because EDMS used FOA 3a in which a multiplier for calculating PMFO is almost 5 times greater than the one using in FOA 3 method. In addition, there are a large difference in none-volatile PM (nvPM) emissions between AEDT and EDMS. This is due to the different versions of EDB used by AEDT and EDMS. EDMS used an older version of EDB, which does not have smoke numbers (SN) available for many TTO aircraft while AEDT has updated EDB which provides updated SN for the TTO aircraft. Since the nvPM calculations are based on SN, EDMS did not calculate nvPM for those aircraft with missing SN. Based on GT's analysis and investigation for the TTO_DULLES study, it can be concluded that AEDT gives equivalent or improved fuel burn and emissions estimations for the TTO aircraft than EDMS does.

Table 5: PM Comparison between AEDT and EDMS with Different Sulfur Factors

		nvPM Mass (lb)	PMSO (lb)*98/96	PMFO (lb)	PM 2.5 (lb)	PM 10 (lb)
AEDT 2c SP1	SFs 2	1.91	28.96	62.76	93.03	93.03
	SFs 1 (default)	1.91	12.01	62.76	76.68	76.68
EDMS 5.1.4	SFs 2	0.68	30.57	288.60	319.85	319.85
Diff (AEDT w/ SFs 2 VS. EDMS)		180.06%	-5.27%	-78.25%	-70.91%	-70.91%
Diff (AEDT w/ SFs 1 VS. EDMS)		180.06%	-60.72%	-78.25%	-76.03%	-76.03%

VALE Report

The Voluntary Airport Low Emissions (VALE) Program is designed to reduce all sources of airport ground emissions. VALE reduction report shows the net differences in emissions between a baseline and an alternative metric result for a single analysis year. This task was focusing on designing test cases to test the VALE report functionalities and to investigate any issues or gaps found in the testing process. GT used 42 test cases, including 15 newly designed test cases and 27 test cases from Volpe, to thoroughly test the VALE functionalities. The functionalities tested include metric results creation, user input for analysis year, VALE report button, End-of-Life year feature, and emissions value comparison. A few issues were found and reported through TFS. The reported issues were resolved by the AEDT development team. GT confirmed that all the VALE functionalities were currently working properly after the bug fixes.

VALE Report 2016 - 2017

Print Preview

Baseline (Source): Base_2010

Alternative (Destination): VALE_2010

Pollutant (Unit): Grams

No.	Year	Scenario	Source Group	CO	VOC	NOx	SOx	PM-10
1	2016	Base_2010						
			Baseline_FuelOilBoiler1 (Stationary Sources)	17,280.000	7,320.000	109,440.000	1,615,680.000	16,992
			Baseline_FuelOilBoiler2 (Stationary Sources)	18,432.000	1,808.470	89,088.000	179,712.000	3,686
			Baseline_GasolineEmergencyGenerator (Stationary Sources)	3,071,923.200	134,073.680	77,184.000	14,356.220	4,137
			Baseline_GasolineAircraftTractor1 (GSE Population)	828,951.840	23,257.070	34,287.040	5,567.220	298
			Baseline_GasolineAircraftTractor2 (GSE Population)	828,951.840	23,257.070	34,287.040	5,567.220	298
			Baseline_DieselAirCond-DieselLavatory (GSE Population)	8,945.850	942.490	23,721.340	10.580	1,493
			Baseline_TrackOps_LightDay_Jan2010	627,167.380	69,971.610	4,756,336.720	313,149.450	113,029
			Baseline_TrackOps_LightDay_Jan2010 (GSE LTO)	902,221.160	29,920.290	83,852.180	4,002.450	3,842
			Baseline_TrackOps_LightDay_Jan2010 (APU)	173,473.630	12,694.600	157,025.770	21,228.860	19,366
			Baseline_TrackOps_HeavyDay_Jan2010	1,537,954.680	163,929.750	5,120,136.660	354,735.790	129,741
			Baseline_TrackOps_HeavyDay_Jan2010 (GSE LTO)	1,156,498.830	38,577.360	109,169.520	5,028.130	4,878
			Baseline_TrackOps_HeavyDay_Jan2010 (APU)	55,166.920	3,887.520	41,839.430	5,878.940	5,869
			Base_2010 Total	**9,226,967.330**	**509,639.910**	**10,636,367.700**	**2,524,916.860**	**303,632.**
		VALE_2010						
			VALE_NaturalGaseBoiler_1_2 (Stationary Sources)	33,331.200	26,331.130	133,324.800	595.200	2,856
			VALE_DieselEmergencyGenerator (Stationary Sources)	46,773.500	15,063.850	216,115.200	14,356.220	15,405
			VALE_DieselAircraftTractor (GSE Population)	17,651.370	1,292.330	44,641.030	20.420	3,140
			VALE_DieselAirCond-DieselLavatory (GSE Population)	8,945.850	942.490	23,721.340	10.580	1,493
			VALE_TrackOps_LightDay_Jan2010	627,167.380	69,971.610	4,756,336.720	313,149.450	113,029
			VALE_TrackOps_LightDay_Jan2010 (GSE LTO)	116,302.270	7,355.740	34,906.850	480.850	1,940
			VALE_TrackOps_LightDay_Jan2010 (APU)	173,473.630	12,694.600	157,025.770	21,228.860	19,366
			VALE_TrackOps_HeavyDay_Jan2010	1,537,954.680	163,929.750	5,120,136.660	354,735.790	129,741
			VALE_TrackOps_HeavyDay_Jan2010 (GSE LTO)	279,579.070	12,963.330	52,087.290	1,085.300	2,629
			VALE_TrackOps_HeavyDay_Jan2010 (APU)	55,166.920	3,887.520	41,839.430	5,878.940	5,869
			VALE_2010 Total	**2,896,345.870**	**314,432.350**	**10,580,135.090**	**711,541.610**	**295,473.**
			2016 Net ER	***-6,330,621.460***	***-195,207.560***	***-56,232.610***	***-1,813,375.250***	***-8,158.***
2	2017	Base_2010						
			Baseline_FuelOilBoiler1 (Stationary Sources)	17,280.000	7,320.000	109,440.000	1,615,680.000	16,992

Figure 2: Example VALE Report

EDMS2ASIF Converter and EDMS Importer

AEDT 2b has the capability of importing studies created with legacy tools such as INM and EDMS. There are two ways to import legacy studies to AEDT: through an external converter tool, which is included with the AEDT installation package or through the built-in importer feature. This task tested the external EDMS2AEDT converter tool and the built-in EDMS importer. As shown in Figure 3, the external EDMS2AEDT converter tool supports importing of EDMS studies by converting the legacy studies into ASIF format first, and then using AEDT to import the converted ASIF to AEDT. On the other hand, the built-in EDMS importer (can be accessed through Study → Import → EDMS) can directly convert an EDMS study to an AEDT study by following the study import wizard. GT successfully used the EDMS2ASIF converter to convert EDMS studies to ASIF files, and then successfully imported the ASIF files to AEDT to create AEDT studies. In addition, GT successfully used the built-in EDMS importer to import 4 EDMS studies to AEDT. The tests verified that the EDMS importer can handle the EDMS study with inconsistent airport data. One bug was found during the process of importing the study and reported through TFS. GT's conclusion is that EDMS2ASIF converter and EDMS importer are functional and working properly.

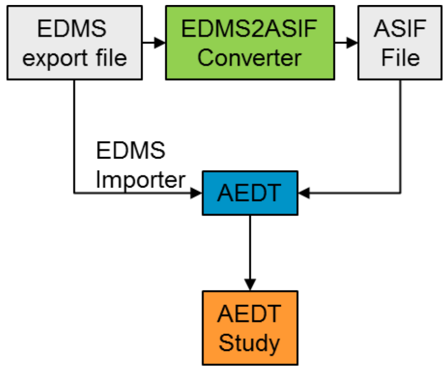

Figure 3: Import EDMS Study through the External EDMS2AEDT Converter or Built-in EDMS Importer

Environmental Justice

One of the key new features added to AEDT 2c is the capability to perform Environmental Justice (EJ) analysis. The EJ capability in AEDT 2c assists identification of potential environment justice populations. According to the *Environmental Desk Reference for Airport Actions* [US FAA, 2016] from the FAA, "Environmental justice analysis considers the potential of Federal actions to cause disproportionate and adverse effects on low-income or minority populations. Environmental justice ensures no low-income or minority population bears a disproportionate burden of effects resulting from Federal actions." In order to use the EJ functionality in AEDT, US Census American Community Survey (ACS) data is required. As of the AEDT 2c release, the ACS data is available for the time period between January 1, 2010 and December 31, 2014. The demographic data is at the Census Block Group level and is approximately 7 GB for the entire US. In AEDT 2c, an EJ analysis is conducted by following the three step work flow: 1) define an EJ boundary, 2) run the EJ analysis, and 3) rerun the EJ analysis by adjusting the analysis thresholds using the EJ analysis pane. AEDT allows the users to define an EJ boundary by either drawing a polygon using the GUI, importing a shapefile, or using pre-computed noise/emission contours.

The EJ capability of AEDT 2c was tested by running four test cases. The first test case used a new AEDT study created from scratch. Two different types of EJ boundaries were created around the San Diego airport. The first boundary was a noise SEL contour that was generated from a study with a single-aisle aircraft departure flight. The second boundary was a user defined polygon around the airport. Test Case 1 showed that the basic functionalities of the AEDT EJ model were working properly. The second and third test cases used DNL contours as EJ boundaries. For Dallas-Forth Worth (KDFW) and Atlanta (KATL) airports, DNL 55, 60, and 65 dB contours were generated for hypothetical future operation schedules using AEDT 2b Feature Pack 1. The DNL contours were exported as shapefiles and then imported into AEDT 2c to use as the EJ boundaries. The tests demonstrated that the shapefiles generated from past AEDT studies could be imported into AEDT 2c and used as EJ boundaries. The EJ analyses were run successfully. Figure 4 shows the EJ test results for the KDFW airport. The Census group blocks that are included in or overlapped with the EJ boundary were colored to indicate whether the block exceeded the poverty rate and/or minority rate thresholds. For example, a Census block shaded blue indicates that both poverty rate and minority rate exceeded the thresholds. Orange color is used to indicate the blocks with high minority and low poverty rate. Yellow is for low minority and high poverty rate. Grey is used when both the thresholds were not exceeded. The thresholds used in this example analysis were 10% for poverty rate and 50% for minority rate, which were set using the GUI in the EJ Analysis pane on the right side of the figure. Users can set the poverty rate and minority rate thresholds using the EJ analysis pane, and then AEDT can almost instantly update the colors for each of the Census blocks. GT confirmed that all of these functionalities associated with EJ capability were working properly.

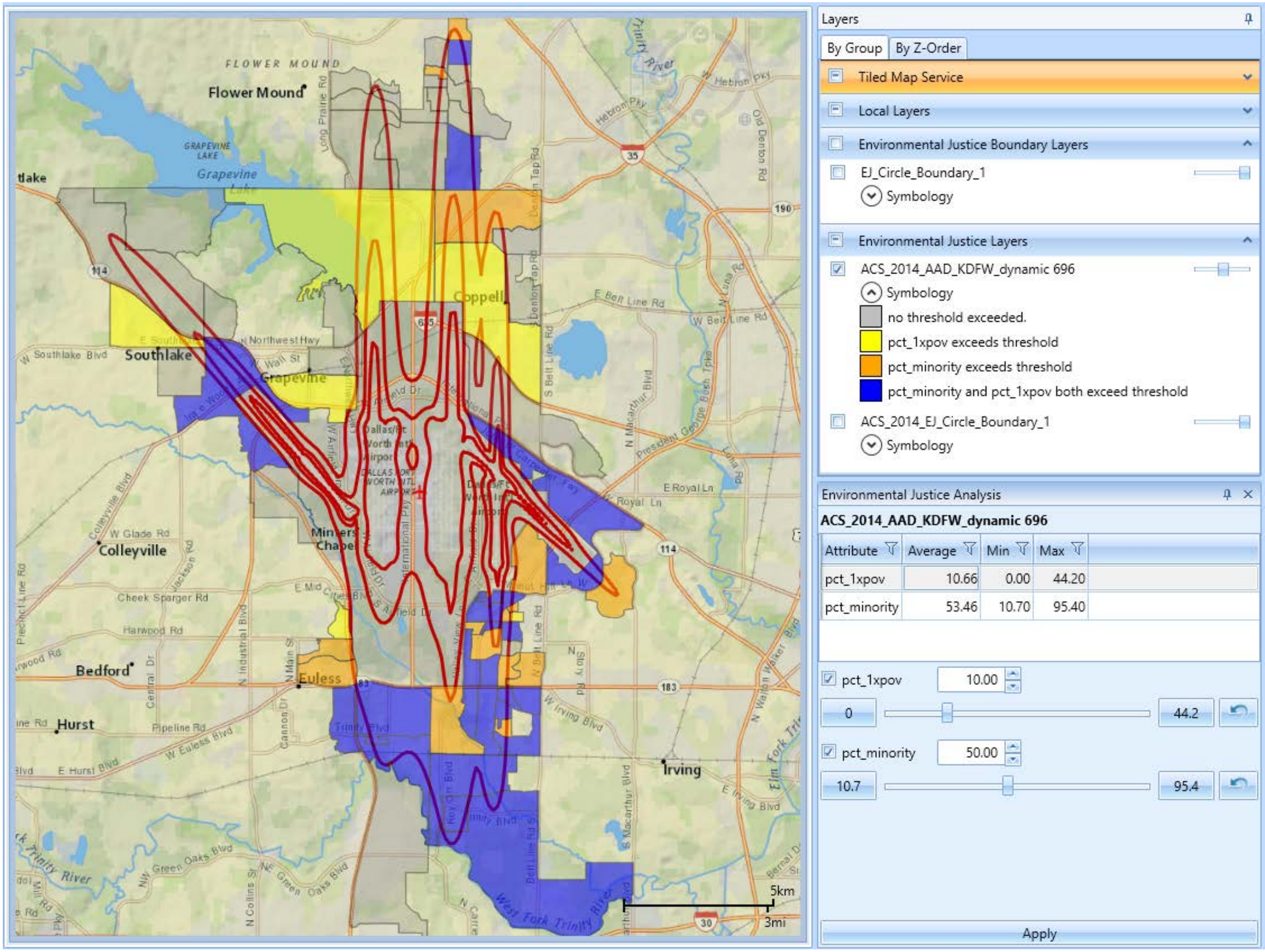

Figure 4: Environmental Justice Analysis Performed Around KDFW for a Sample DNL 55, 60, and 65 dB Contours

Typically, an EJ analysis would be conducted around an airport using either noise or emission related metric results. However, AEDT's EJ functionality is not limit to the vicinity of an airport. Another EJ test was performed to demonstrate that an EJ study can be performed at any location without a metric result. An EJ boundary was created around a random location in Dekalb County, Georgia. A circular EJ boundary with a 6-mile radius was created in AEDT. The EJ analysis was run successfully for the circular boundary and the results are shown in Figure 5. The EJ Layer pane on the right side of the figure explains what the color scheme means. AEDT allows the users to display the Census data for the Census blocks included in the EJ study. It is also possible to export the data into an Excel spreadsheet for further analysis. The data table shown in the bottom of Figure 5 includes the raw ACS data. Users can select a Census Block by clicking a row in the table, and then the boundary of corresponding block on the map gets highlighted. The US Census ACS data include demographic data other than poverty rate and minority rate. AEDT allows the users to change or add demographic parameters and run EJ analyses. This functionality was successfully tested by adding median household income as the third parameter.

A couple of minor bugs on GUI were found and reported through TFS, and were fixed for the subsequent sprint releases. In addition, some potential areas of improvements were identified and reported to the development team as well. Currently, AEDT does not allow the users to change the color scheme for the EJ map. The fixed color scheme works reasonably well when two EJ parameters are used for the analysis. However, when more than two parameters are used, the fixed color scheme cannot represent all the combinations of potential analysis outcomes. For example, when median household income, poverty rate, and minority rate are used for an EJ analysis, AEDT can use the same color for 1) low median household income, high poverty rate, and high minority rate and 2) high median household income, high poverty rate, and high minority rate. At the moment, it is advised to use two demographic parameters at a time.

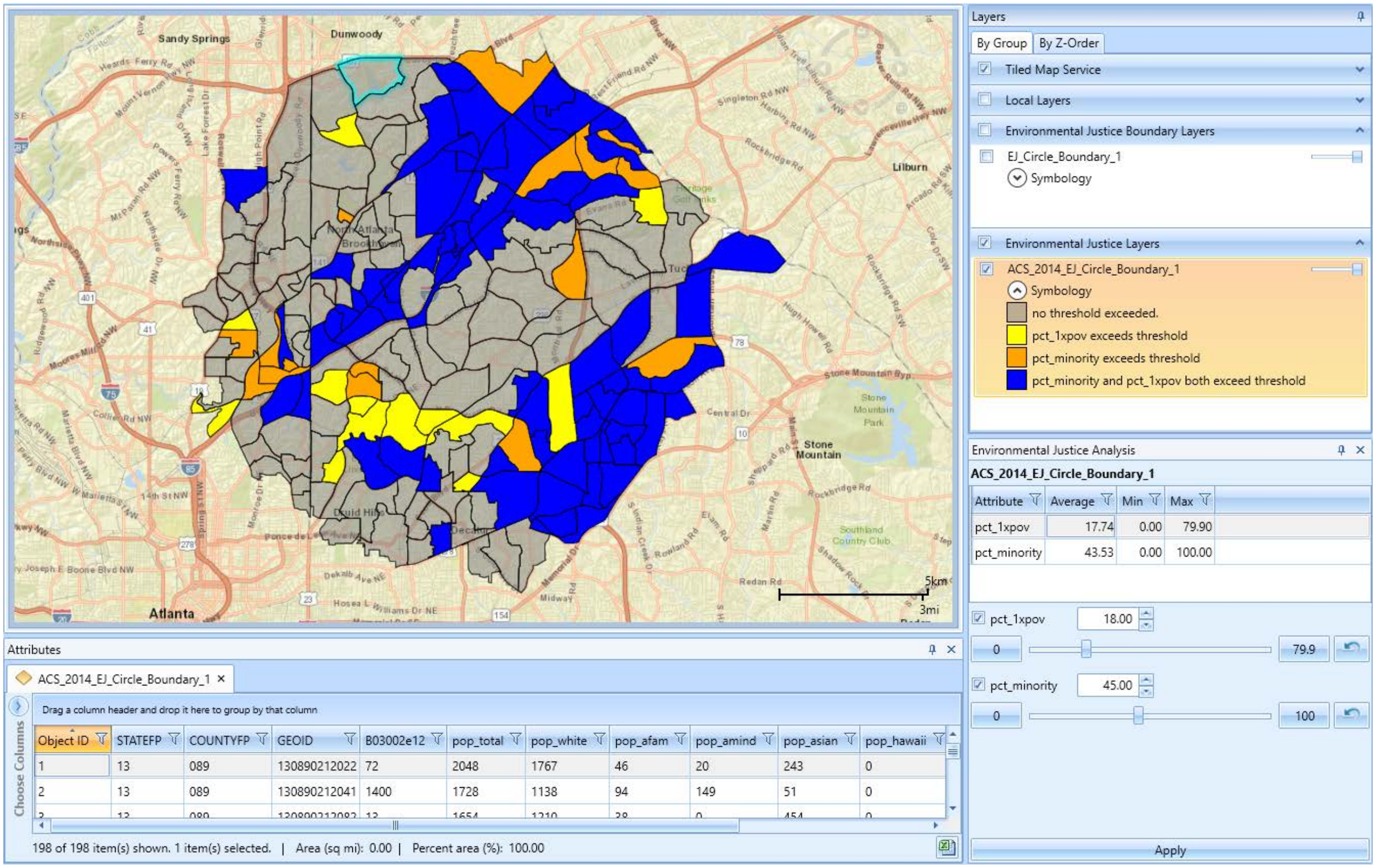

Figure 5: An EJ Analysis Using a Circular EJ Boundary Created in DeKalb Country, Georgia

AEDT allows the users to export the EJ analysis result as a shapefile along with the associated demographic data for the Census blocked included in the shapefile. This functionality was tested by exporting the EJ analysis for KDFW. Then the shapefile was imported into ArcGIS, one of the widely used geographical information system (GIS). When the shapefile was imported, ArcGIS also imported the raw EJ data for the Census Blocks that were included in the EJ analysis. ArcGIS provides various ways to present the EJ data. Figure 6 shows an EJ analysis for KDFW conducted in ArcGIS. The Census block groups were colored by poverty rate. Pie charts represent population size and racial composition of the Census block. AEDT combined with ArcGIS provide very powerful and convenient analytic capability to investigate EJ issues due to environmental impacts from aviation.

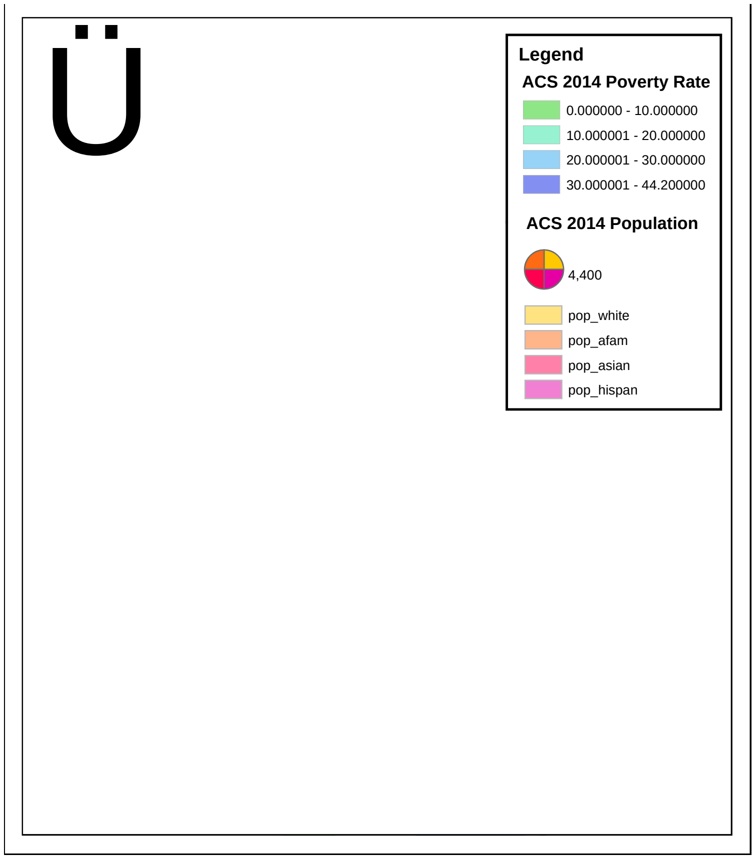

Figure 6: An EJ Analysis for KDFW in ArcGIS Using the Shapefile and Demographic Information Imported from AEDT

Atmospheric Absorption Models

As aircraft noise propagates through the atmosphere, the sound energy dissipates at a rate determined by the atmospheric condition. Relative humidity and air temperature affect the degree of atmospheric absorption most. Figure 7 shows atmospheric attenuation in dB/1000 ft as a function of temperature and relative humidity [Landrum and Brown, 2013]. The figure shows that the degree of atmospheric absorption depends on the frequency of the sound wave. INM and AEDT2a provide two atmospheric absorption models [US FAA, 2014]. The default atmospheric absorption model has been the SAE-AIR-1845. The SAE-AIR-1845 method specifies how the Noise-Power-Distance (NPD) curves are created by normalizing the measured aircraft noise for the standard atmospheric condition. When SAE-AIR-1845 is used as the atmospheric absorption model in INM or AEDT, the NPD curves based on the standard day atmosphere are used without any adjustments. When SAE-ARP-866A model is selected and non-standard, airport specific atmosphere is used, the NPD curves are adjusted to reflect the different atmospheric attenuation rates for the airport atmosphere. The SAE-ARP-866A model adjusts the NPD curves for the non-standard relative humidity and temperature for each of the 1/3rd-octave bands. AEDT 2b implemented an improved atmospheric absorption model based on SAE-ARP-5534, where the NPD curves are adjusted for relative humidity, temperature, and atmospheric pressure.

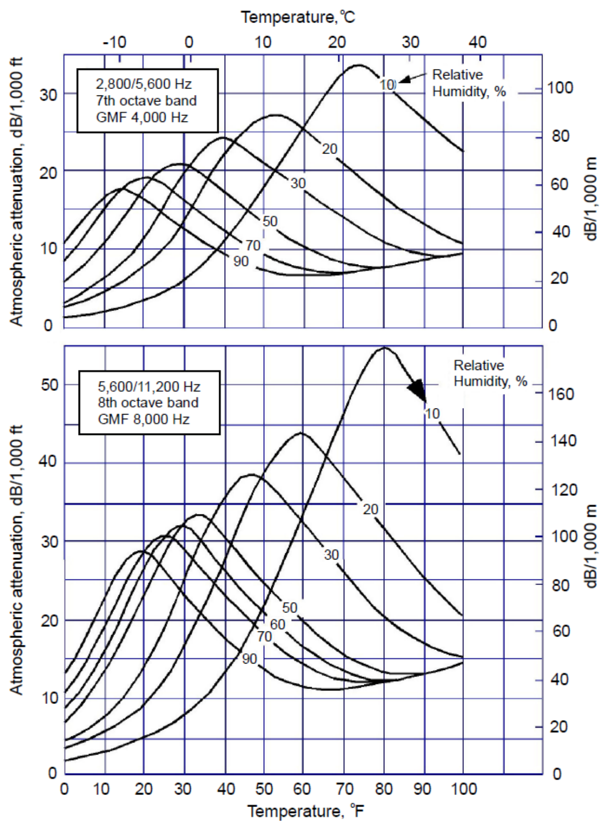

Figure 7: Atmospheric Sound Attenuation Graph

Since airport noise analyses before the release of AEDT 2b were conducted either using SAE-AIR-1845 or SAE-ARP-866A, a sensitivity analysis was conducted to investigate how much noise contours would change based on the selection of an atmospheric absorption model. Sensitivity of noise impacts from atmospheric absorption model was measured in terms of differences in SEL and DNL contour areas. Five different US airports were selected for the study to represent from a small airport with a single runway to medium and large hub airports with complex runway configurations. For the selected five airports, DNL 55, 60, and 65 dB contour areas were calculated for a 2012 average day operations. Table 6 shows the DNL 55, 60, and 65 dB areas for the five studied airports for the three atmospheric absorption models. Based on the results, the SAE-ARP-866A model resulted in greater contour areas than the SAE-AIR-1845 model for all the five airports. Subsequently, the use of SAE-ARP-5543 model resulted in greater contour areas than the SAE-ARP-866A model. For airports Large Hub 2 and 3, the differences between the SAE-ARP-886A/ SAE-ARP-5534 and SAE-AIR-1845were greater for the 55 dB level. For other three airports, the differences due to the different absorption models were close for the three dB levels. Depending on the airport, the use of SAE-ARP-5543 increased the DNL 65 dB contour areas from 7.6% to 16.7% compared to SAE-AIR-1845. Therefore, it is very important to make sure that a consistent absorption model is used when two noise studies are compared. Noise modelers should be very careful comparing past study results from INM or AEDT2a to the updated results from AEDT 2b or AEDT 2c since the atmospheric absorption modes may be different.

Table 6: Comparison of DNL Contour Areas for Different Atmospheric Absorption Models

Airport	DNL (dB)	Contour Areas in Sq Miles				
		SAE-AIR-1845	SAE-ARP-866A		SAE-ARP-5534	
		Area	Area	Diff	Area	Diff
Busy Single Runway	55	19.1	22.0	15.3%	23.0	20.6%
	60	7.4	8.4	14.0%	8.7	18.9%
	65	2.8	3.2	12.4%	3.3	16.0%
Large Hub 1	55	68.7	79.4	15.6%	82.8	20.6%
	60	29.1	33.4	15.0%	35.1	20.8%
	65	12.4	13.9	12.1%	14.4	16.5%
Large Hub 2	55	57.5	74.1	29.0%	80.6	40.2%
	60	21.9	26.5	20.8%	28.3	29.3%
	65	9.5	10.7	12.2%	11.1	16.7%
Large Hub 3	55	25.0	31.4	25.7%	34.2	36.9%
	60	8.0	9.4	17.5%	10.0	25.3%
	65	2.8	3.1	10.4%	3.2	13.8%
Medium Int'l	55	46.6	48.2	3.4%	49.4	6.0%
	60	20.4	21.4	5.0%	22.0	7.8%
	65	8.3	8.7	5.1%	8.9	7.6%

The choice of atmospheric absorption model not only impacts the size of the noise contours area but also affects the contour shape. For airports with single runway with relatively straight flight tracks, the choice of the three absorption models may proportionally scale the noise contours. However, for airports with complex contour shapes due to intersected runways and/or curved flight-tracks, the selection of an absorption model can also impact the shape of the contours. Figure 8 compares the DNL 55, 60, and 65 dB contours for KJFK. The general shapes are similar for the SAE-AIR-1845 and SAE-ARP-5543 models. However, the overall increase in noise levels with the SAE-ARP-5543 model changed the contour shapes. For the SAE-ARP-5543 model as shown at the bottom of the figure, the two DNL 55 dB noise lobes for thesouth-westerly departures were merged.

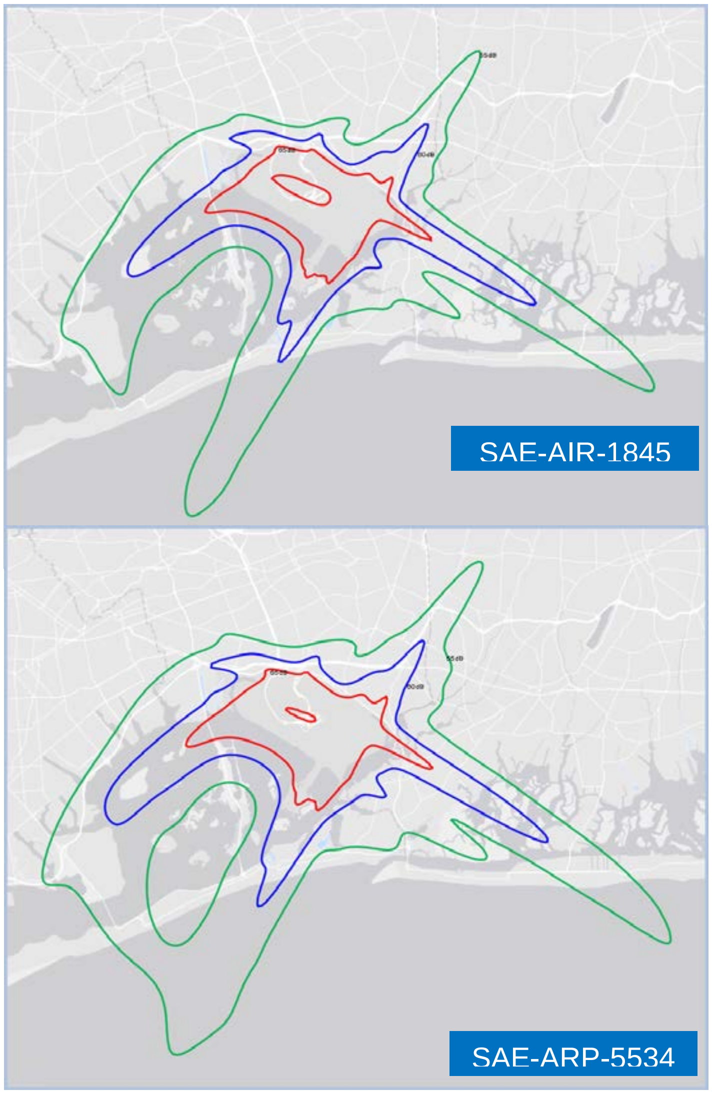

Figure 8: Comparison of DNL Contours at KJFK

Noise Contouring Algorithm

As part of the ASCENT 11b effort, GT conducted noise analysis using AEDT 2b Feature Pack 1 for 38 US airports for three technology scenarios. In some cases, AEDT failed to generate contour plot and/or calculate the areas properly. For theairports in those cases, contour areas were calculated through a MATLAB script developed by GT using the noise reports exported from AEDT. It was found that AEDT and MATLAB showed large differences in contour areas for some cases. GT found out that the issue was that the AEDT contouring algorithm did not properly account for contour holes and islands, and this issue was reported The development team quickly fixed the problem and GT confirmed that the new contouring algorithm worked for all 38 airports. As an example, Figure 9 shows DNL 55, 60, and 65 dB contours for an airport with parallel intersected runways, and the analysis was conducted using AEDT 2b Feature Pack 1 which used the old algorithm. As can be seen from the figure, the 65 dB contour in red appears as a very small island. The contour areas and lengths shown in the table within the figure also indicates disproportionately small 65 dB contour. Figure 10 is the reanalysis of the same study using the new AEDT contouring algorithm after the bug fix. It shows the main 65 dB contour with two contour holes and a small contour island, and the contour lengths and areas in the table are in the right proportion compared to the 55 and 60 dB contours. GT compared the contour areas calculated using MATLAB code and confirmed that the updated AEDT contouring algorithm worked properly for the 38 US airports used in this investigation.

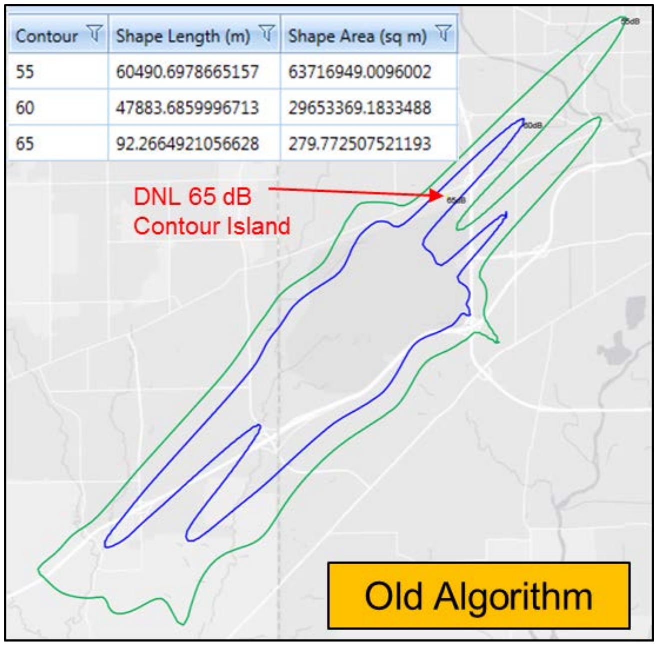

Figure 9: DNL 55, 60, and 65 dB Contours for an Airport Generated in AEDT 2b

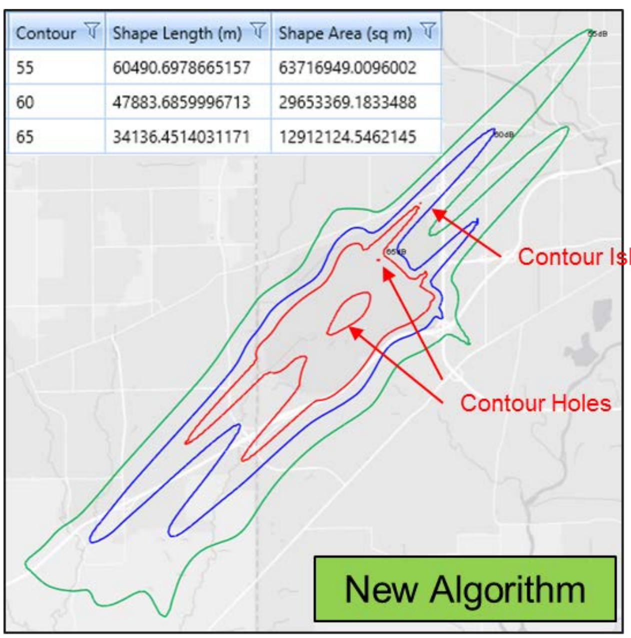

Figure 10: DNL 55, 60, and 65 dB Contours for an Airport Generated in AEDT 2c

Population Exposure Calculation

As part of the ASCENT 11b effort, GT also calculated population exposure in AEDT for 38 US airports. The purpose was to compare noise contour areas and population exposure counts between AEDT and the GREAT tool, which was developed under ASCENT Project 11b. GT identified some issues with population exposure numbers from AEDT. The issue was that for some airports for particular DNL levels and technology scenarios, the population from AEDT was unreasonable small compared to the numbers calculated by GREAT when the contour shapes and sizes were similar. Another issue was that AEDT would fail to calculate population for some airports in a random manner. It would work one day and would not work the next day for the same study. After investigation with the AEDT development team, the first issue was found to be related to the contouring algorithm not properly accounting for the contour islands and holes. AEDT uses two separate geographic processing packages for contour generation and population exposure calculation. The issue was resolved by updating the AEDT GIS module that creates population grids from Census data. The second issue of AEDT's random error with population calculation was related to the caching mechanism, which caused errors when the UTM zones were different. The development team implemented a temporary fix to the problem by disabling the Census caching mechanism. The development team is looking into a permanent fix.

Time Audible Noise Metrics

One of the important enhancements to AEDT 2b SP3 is the addition of Time Audible (TAUD) noise metrics. The four TAUD metrics added to AEDT 2b are TAUD (Time Audible), TAUDP (Time Audible Percent), TAUDSC (Time Audible Statistical Compression), and TAUDPSC (Time Audible Percent Statistical Compression). Audibility or Detectability is the ability for an attentive listener to hear aircraft noise. Audibility depends on both the aircraft sound level ("signal") and the ambient sound level ("noise"). Although DNL is the most widely used noise metric for airport noise analyses, TAUD has been an important metric measuring noise impacts at National Parks.

Using AEDT 2b SP3 and later versions, GT has been testing the TAUD metrics for a study created for the Acadia National Park. At the Acadia National Park, four different types of aircraft operations were created using different types of aircraft. The tests are still in progress, but the preliminary results show that AEDT is calculating TAUD metrics correctly. Figure 11 shows TAUD results from a single-aisle aircraft departure at the KBHB airport near the Acadia National Park. The TAUD results that are shown on the right range from 0 to 3.5 minutes depending on the receptor location. The maximum of 3.5 minutes corresponds to the time duration from the start of take-off roll to the end of climb at 10,000 ft as shown on the trajectory plot. The next steps in TAUD tests include comparing TAUD results between INM 7.0d [Boeker, et.al, 2008; ATAC, 2007] and AEDT for departure, arrival, over-flight, and circuit flights.

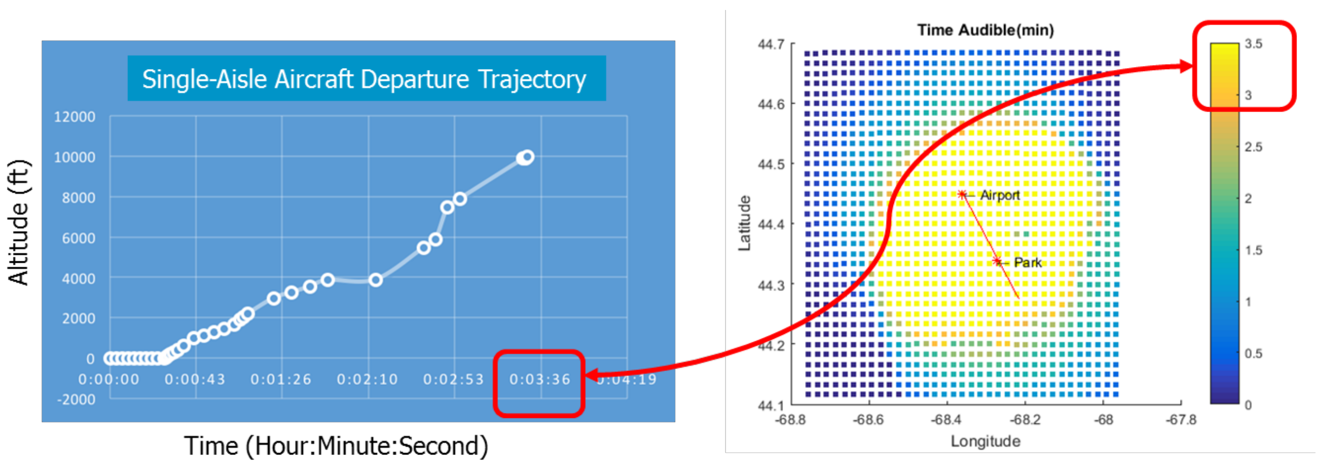

Figure 11: A Single-Aisle Aircraft Departure Trajectory and TAUD Results in Acadia National Park

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	

Major Accomplishments

Starting from May 2016, GT has tested all the new AEDT versions released including Sprints from 70 to 79. Sprints 70 – 79 included three public versions of AEDTs, namely AEDT 2b SP3, AEDT 2c, and AEDT 2c SP1. GT tested the ten versions of AEDT 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 improved VALE reporting capability, implementation of TTO aircraft fuel burn and emission calculations, implementation of Environmental Justice capability, the addition of TAUD and NA noise metrics, improved nvPM calculations, the addition of background emission concentration, and new features on emission dispersion display. In order to understand the background of new AEDT features, GT reviewed all the relevant documents including the software requirement documents, Database Design Document, AEDT sprint release notes, updated technical manual, user manual, and research papers/reports. GT has conducted basic testing of all the new AEDT versions to confirm its functionality. GT identified 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. In addition, GT also reported any potential areas of improvements in AEDT algorithm and user-friendliness.

Publications

None

Outreach Efforts

None

Awards

None

Student Involvement

Evanthia (Eva) Kallou is a second 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, and AEDT2c.

Junghyun (Andy) Kim is a second year PhD student who started in fall 2015. Mr. Kim has conducted a literature review on UQ methods. Mr. Kim is being trained on related tools such as INM, AEDT Tester, and AEDT2c.

Plans for Next Period

GT will continue Task 1 and 2 for new AEDT 2c releases. AEDT 2c SP2 is planned to be released in mid-March 2017. GT will perform Task 1 and 2 for the preliminary versions of AEDT 2c SP2 to identify any issues that need to be addressed by the development team.

Task 1. Proper Definition of AEDT Input Parameter Uncertainty
As discussed above.

Task 2. Verification and Validation plus Capability Demonstrations
As discussed above.

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.

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.

Additional Tasks for Next Period

For the work period of 12/1/2016 to 3/31/2017, GT will perform the following additional tasks per the augmented project plan. Building on prior UQ research efforts, GT will coordinate with the FAA/AEE on the details of the specific tests to understand the differences in the use cases between the legacy tools and AEDT2b for the following use cases. In some instances, additional analysis will be conducted; and in other cases, only clarification to the original UQ report will be provided.

Task 1 – Use Case A – Inventory Analysis
For Use Case A, sufficient analysis was conducted in the UQ report. However, the FAA desires a more thorough discussion on the results obtained. As such, GT will add a more detalied discussion. To accomplish this task, GT will need the AEDT study DB utilized for this use case.

Task 2 – Use Case B and C– NEPA/CAA Analysis
The purpose of Use Cases B and C was to provide a capability demonstration of AEDT 2b functionality and a comparison to the Emissions and Dispersion Modeling System (EDMS) at PVD airport. For Use Case B, operational profiles were utilized with AEDT2b Service Pack 2 62.3.43546.1 and EDSM 5.1.4.1. For Use Case C a detailed schedule of aircraft operations was utilized in lieu of operational profiles, and AEDT2b Service Pack 1 62.3.43302.1 and EDSM 5.1.4.1 were used for the analysis. There were a number of discrepancies between AEDT2b and EDMS. GT will conduct the following tasks to enhance the UQ report for both Use Cases:

1. Data analysis by source types and aircraft categories to identify major source of discrepancy
2. Run a single flight study to help investigate the major source that makes the difference
3. Compare flight trajectories to see the differences in APM modules
4. Investigate the causes that lead to the difference between AEDT and EDMS
5. Justify if the difference is reasonable or not

6. Recommend the solutions for improving the results if there is any

To accomplish this task, GT will coordinate with the FAA on the proper version of AEDT2b release to use. The same version will be utilized for both use cases for consistency.

Task 3 – Use Case D – Part 150 Analysis
The purpose of this Use Case was to evaluate the capability of AEDT 2b for performing a Part 150 airport noise analysis and to test other aircraft noise modeling functionality of AEDT 2b. Historically, Part 150 analyses were performed with the legacy Integrated Noise Model (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.

In the Phase I of this Use Case, a number of large differences were observed between AEDT2b and INM. Through prior research, GT had identified a contour algorithm bug that could have been the source of discrepancies. As such, GT will redo the noise analysis at the airports with large errors and include ANC, JFK, HNL, and SFO. Additional investigations will be done on the absorption model and the engine installation, and new results will be documented.

For Phase II, the goal was to test the specialized functionality that consists of other noise modeling functionalities that are not always included in Part 150 studies but may be used in specialized noise analyses, for example, atmospheric absorption adjustment over a range of meteorological conditions (SAE-ARP-5534, SAE-ARP-866A). Differences were observed for this Use Case and GT will investigate the source and document the findings. To accomplish this effort, GT will need the AEDT Studies for AIRMOD and UCD.

Task 4 – Use Case E - Part 1: Air Traffic Airspace and Procedure Analysis
The purpose of Use Case E, Part 1, was to test AEDT 2b's capability for performing noise impact, fuel consumption, CO_2 production, and emissions calculations to support a NEPA study for an applicable airspace redesign study. This type of NEPA study was conducted as part of this uncertainty quantification effort in order to validate that AEDT 2b has the necessary functionality and capability to perform this type of applicable analysis.

In general, there was good agreement between AEDT2a and 2b. A few differences were observed for LAMAX. GT will investigate the differences and document them.

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