U.S. Department
of Transportation
Federal Aviation
Administration

Aviation Environmental Design Tool (AEDT) 2a

Uncertainty Quantification

Executive Summary

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1 Overview

This document provides a summary of the Federal Aviation Administration's (FAA) uncertainty quantification effort for the Aviation Environmental Design Tool Version 2a (AEDT 2a). The intent of this documentation is to inform and educate the user regarding the thorough expert review, verification, validation, capability demonstration, parametric uncertainty/sensitivity analysis and other relevant testing that went into the development of AEDT 2a. The full length *AEDT Version 2a Uncertainty Quantification Report* provides complete documentation by delving into greater detail on the uncertainty quantification activities and their results. This document is intended to serve as a summary of the uncertainty quantification effort for AEDT 2a.

AEDT is a software system that models aircraft performance in space and time to quantify fuel consumption, emissions, and noise. 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 is being released in two phases. The first version, AEDT 2a, was released in March 2012 and is used for air traffic airspace and procedure actions where the study area is larger than the immediate vicinity of the airport, incorporates more than one airport, and/or includes actions above 3,000 feet above ground level (AGL). AEDT 2a replaces FAA's current analysis tool for these applicable analyses, the Noise Integrated Routing System (NIRS), and is able to perform environmental analysis for airspace actions under the National Environmental Policy Act (NEPA). This version is the focus of this uncertainty quantification effort.

The second version, AEDT 2b, is targeted for release in 2014. In addition to containing all of the capabilities of AEDT 2a, it will replace the following current public-use aviation air quality and noise analysis tools: the Emissions and Dispersion Modeling System (EDMS – single airport emissions analysis) and the Integrated Noise Model (INM – single airport noise analysis).

The AEDT development cycle includes rigorous testing of all levels of software functionality from the individual modules to the overall system. However, the FAA's Office of Environment and Energy sought a robust uncertainty quantification effort in addition to this test program. This uncertainty quantification comprehensively assesses the accuracy, functionality, and capabilities of AEDT 2a during the development process. The major purposes of this effort are to:

- Contribute to the external understanding of AEDT 2a
- Build confidence in AEDT 2a's capability and fidelity (ability to represent reality)
- Help users of AEDT 2a to understand sensitivities of output response to variation in input parameters/assumptions
- Identify gaps in functionality
- Identify high-priority areas for further research and development

The uncertainty quantification consists of four major elements: expert review, verification and validation, capability demonstrations, and parametric uncertainty/sensitivity analysis. A summary of the work in each of these four areas is presented in the following sections.

2 Expert Review

The FAA's Office of Environment and Energy has actively encouraged the input of academia, government agencies, and industry to guide the methodologies, algorithms, and processes implemented in the AEDT 2a software. As a result, key expert organizations have reviewed AEDT 2a throughout its entire development cycle.

The AEDT Design Review Group, composed of a diverse international group of future users and stakeholders, met regularly during the AEDT 2a development process and provided valuable feedback to the development team through its use of development versions of the software.

SAE International's Aircraft Noise Measurement and Aircraft Noise/Aviation Emission Modeling Committee (A-21) and its publications[1,2,3,4] provided the basis for many of the core flight performance, noise, and emissions calculations in AEDT 2a.

European Civil Aviation Conference (ECAC) *Report on Standard Method of Computing Noise Contours around Civil Airport* (Document 29)[5] also guided the development of AEDT methodologies for noise and flight performance modeling. AEDT 2a has been built to comply with this internationally accepted noise modeling standard.

The International Civil Aviation Organization (ICAO) Committee on Aviation Environmental Protection (CAEP) Modeling and Database Task Force evaluated a range of current and proposed tools that model aircraft noise, air quality, and emissions, including AEDT. The effort assessed functionality of each tool and the tool's ability to meet the current and future modeling needs of CAEP. AEDT was evaluated in all three areas: aircraft noise, air quality, and emissions, as part of this exercise. The assessment showed that AEDT matched or exceeded the number of criteria satisfied by the other tools in each area.

Additionally, many of the modeling methodologies in AEDT 2a have been carried forward from legacy software tools NIRS, INM, and EDMS; and, consequently, AEDT 2a has gained from the extensive guidance and review that such organizations have provided to these legacy software tools.

3 Verification and Validation

Validation and verification (V&V) consists of a set of activities that ensure AEDT 2a meets its design objectives. These activities are primarily a comparison of AEDT 2a's methods and analysis results to those of legacy tools. This V&V includes the following:

- Verification of AEDT 2a's databases to the appropriate "gold standard" data sources
- Verification of AEDT 2a standard input data
- A detailed comparison of flight paths between AEDT 2a and NIRS for sample studies
- A detailed comparison of noise between AEDT 2a and NIRS for a variety of test cases

- A discussion of emissions calculation methodology, as compared to EDMS
- An analysis of AEDT 2a's ability to define a flight path with real world sensor data
- An analysis of the newly developed weather features
- An analysis of the effect of the transition between the two aircraft flight performance methodologies that AEDT 2a employs for different altitude regimes

Further description of these V&V activities is provided below.

3.1 Input Data Pedigree

The AEDT development team has worked to confirm the pedigree of the input data that form the basis for AEDT 2a's calculations. Verification of AEDT's Fleet and Airports Databases was made against the definitive source data. Both databases have been exercised throughout the testing of the tool and are considered to be mature and reliable.

Validation of noise and flight performance data was documented. Both legacy and current practices were covered. Current validation of aircraft noise and flight performance data includes data review for consistency and reasonableness, comparison against existing data for similar aircraft in the AEDT Fleet Database, verification of the acceptability of the data over a wide range of modeling conditions, sensitivity analyses to determine impacts due to the new data, and comparison of model runs with real world results, where possible. Fuel consumption data and fuel consumption calculation methods were validated by comparing AEDT 2a model outputs with values obtained from commercial aircraft flight data recorders.

3.2 Comparison to Legacy Tools

Since AEDT 2a replaces an existing legacy software tool, NIRS, it must demonstrate an ability to analyze the same scenarios and generate results where differences from NIRS are reflections of algorithmic or methodological improvements in AEDT 2a. To this end, a number of sample cases were analyzed with both AEDT 2a and NIRS. Both noise and flight performance were evaluated.

A comparison of flight path outputs between AEDT 2a and NIRS was conducted for real-world sample studies that include a large number of operations. Discrepancies in the results between the two programs were driven by intentional algorithmic differences between the tools. Agreement was seen where expected. Aggregated characterization of the differences was deemed acceptable and within expectations for the intentional differences in the tools. These differences reflected improvements in the flight performance methodology in AEDT 2a.

Noise was also evaluated in AEDT 2a and NIRS for a number of test cases. The handling of environmental parameters and terrain were evaluated. Additionally the noise exposure results for a set of fifteen test aircraft were compared between the two tools. The majority of the differences observed are related to flight performance modeling upgrades in AEDT 2a, providing confidence in the tool and highlighting what a new user may expect with AEDT 2a. The noise tests did uncover a bug in the handling of lateral attenuation of noise for NOISEMAP derived ANP military aircraft models. This bug resulted in lower noise exposure in AEDT 2a than in the NIRS legacy tool for these military aircraft models. The bug has been resolved in AEDT 2b development and is under consideration for an AEDT 2a service pack. (It should be noted that if this issue were not fixed within an AEDT 2a service pack, the fixes will be present in AEDT 2b, which will contain all of AEDT 2a's capability for applicable analyses.) Additionally, the Shorts Brothers SD330 aircraft showed AEDT 2a calculating lower noise exposure than in NIRS. Further investigation confirmed that this is not an issue with the handling of turboprop aircraft in general, and it appears to affect only this aircraft. Since the SD330 aircraft represents a very small portion of operations in the national airspace system, the issue will be further investigated for correction in AEDT 2b. Otherwise, all of the other aircraft cases analyzed showed AEDT 2a in agreement with NIRS with any discrepancies explained by the intentional algorithmic and methodological differences between the programs.

The emissions calculation methods in AEDT 2a are consistent with those used in the legacy tool, EDMS. As a result, any differences that would be observed in an analytical comparison between EDMS and AEDT emissions results for Version 2a would be the result of intentional algorithmic changes in the aircraft performance modeling and/or database updates. The performance modeling features of AEDT 2a and key differentiators from legacy tools were thoroughly evaluated in other sections of the V&V work.

3.3 Evaluation of New Functionality

As part of the V&V effort, new functionalities in AEDT 2a were evaluated and impacts of these new functionalities were assessed.

An assessment of AEDT 2a's capability to use sensor data (radar, ADS-B, flight data recorder, etc.) to define a flight path was completed. The tool filters the input altitude and speed data to ensure that noise in this data does not compromise model outputs. Demonstration of this capability was successful.

One of many improvements in AEDT 2a is the expanded weather capabilities, which include the option to use more detailed weather data than was possible in legacy tools. AEDT 2a is also able to more accurately calculate the effects of weather on aircraft flight performance regardless of the weather source. These detailed weather features have been assessed, exercised in the tool, and test cases have been used to show that the effects of detailed weather meet physical expectations.

AEDT 2a has implemented the best suited aircraft performance methodologies for different altitude flight regimes. A method was developed for handling the transition at 10,000 feet above field elevation, below which computations are based upon SAE-AIR-1845 and ECAC Document 29, and above which EUROCONTROL Base of Aircraft Data (BADA)[6] performance algorithms are used. AEDT 2a's method of transition between these two flight performance methodologies was validated through several analyses, including comparisons to information from aircraft flight data recorders.

4 Capability Demonstration

In order to evaluate usability and key functionality requirements of AEDT 2a, uninitiated users were asked to use AEDT 2a to walk through the steps of conducting a NEPA study for an applicable airspace redesign project. The tool was determined to have the functionality necessary to perform the noise impact, fuel consumption, CO_2 production, and other emissions calculations required for this type of applicable analysis. This capability demonstration has shown that AEDT 2a satisfies its purpose as a tool for conducting environmental impact analyses in support of NEPA requirements.

The functional capabilities of AEDT 2a were also assessed by using it to perform sample applicable airspace studies of the Cleveland/Detroit and New York/New Jersey airspaces. These two studies were based on real-world airspace studies, with modifications made to ensure fair comparison between AEDT 2a and the legacy tool for this type of analysis, NIRS. Results from AEDT2a and NIRS for the two studies were compared directly. The results generated by AEDT 2a and NIRS for the Cleveland/Detroit and New York/New Jersey studies compared favorably, with some exceptions driven by intentional algorithmic differences between the tools that reflect improvement in AEDT 2a.

5 Parametric Uncertainty and Sensitivity Analysis

Finally, a global sensitivity statistical analysis was conducted to quantify the degree to which variation in data inputs are propagated to tool outputs. A survey of the key algorithmic modules and input parameters was made to identify potential variability within these inputs. A number of Monte Carlo simulations were run in which these inputs were adjusted across their range of variability for five representative airport studies. The results were used to quantify the contribution of different inputs on key output results, including noise contour area, fuel burn, carbon dioxide, oxides of nitrogen, carbon monoxide, hydrocarbons, sulfur dioxide, and particulate matter. Results from the parametric sensitivity analysis show which inputs are of higher relative importance for conducting an accurate analysis. The most influential inputs are primarily system data, such as aircraft performance coefficients, which are not user affected. Of particular interest to the user, atmospheric parameters were shown to have consistent contributions to variability in noise, fuel consumption, and emissions. This was observed for all of the examined airports.

6 Conclusions

The AEDT 2a uncertainty quantification effort sought to quantify AEDT 2a's overall utility to meet its intended purpose as a software tool for evaluating the environmental consequences of aviation operations. This work was performed to build confidence in AEDT 2a's capability, fidelity, and connection to the precedent of the legacy tools it replaces. This confidence is derived from the expert review that has been conducted throughout the tool's development history, a verification and validation of the software's methodologies and performance in comparison with legacy models and "gold standard" data, a demonstration of its capability to conduct the analyses for which it was designed, and a parametric uncertainty/sensitivity analysis that informs both user and developer for future use and development, respectively.

The detailed documentation of these efforts is presented in the full *AEDT 2a Uncertainty Quantification Report*.

References

[1] Society of Automotive Engineers (SAE) Aerospace Information Report (AIR) 1845 (SAE-AIR-1845), *Procedure for the Calculation of Airplane Noise in the Vicinity of Airports*, March 1986.

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[4] Society of Automotive Engineers (SAE) Aerospace Recommended Practice (ARP) 866A (SAE-ARP-866A), *Standard Values of Atmospheric Absorption as a Function of Temperature and Humidity*, March 2005.

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[6] European Organisation for the Safety of Air Navigation, EUROCONTROL Experimental Centre, EEC Technical/Scientific Report No. 11/03/08-08, *User Manual for the Base of Aircraft Data (BADA), Revision 3.9*, Brétigny-sur-Orge, France, March 2011.