# Project 036 Parametric Uncertainty Assessment for AEDT 2b

## Georgia Institute of Technology

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- FAA Award Number: 13-C-AJFE-GIT, Amendment 014
- Period of Performance: August 1, 2015 – January 31, 2016
- Task(s):
    1. Proper Uncertainty Definition of AEDT Input Parameter
    2. Identification of Important Output to Input Relationships
    3. Guidelines for Future Tool Research

## Project Funding Level

Funding from the FAA is $65,000 for 6 months. The Georgia Institute of Technology has agreed to a total of $65,000 in matching funds.

## Investigation Team

Prof. Dimitri Mavris, Dr. Michelle Kirby, Dr. Don Lim, Dr. Yongchang Li, Evanthis Kallou (Graduate student), with consultation/support by graduate students: Matthew Levine, Fatma Karagoz, and Junghyun Kim and research staff Dr. Holger Pfaender and Mr. Chris Perullo

## 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 valuations. At the heart of this tool suite is the high fidelity Aviation Environmental Design Tool (AEDT). AEE is interested in performing a system level parametric uncertainty analysis on the Aviation Environmental Design Tool (AEDT). This system level assessment will quantify how input uncertainties propagate through the system and contribute to uncertainty in overall policy outcomes.

The objective of this research is to perform a more meaningful system level parametric uncertainty analysis on AEDT Version 2b. This investigation requires expertise in aircraft design and mathematical formulations, especially with respect to uncertainty and sensitivity analysis, in addition to properly modeling the relationships of the input parameters to AEDT 2b. The task outcome will be used for a multitude of items, specifically 1) to identify gaps in the tools functionality and areas for further development, 2) contribute to the development of external understanding of the FAA tools suite capabilities, 3) provide a sensitivity analysis of the output response to uncertainties in input parameters and assumptions, and 4) establish a new approach for future uncertainty quantification (UQ) efforts.

The research conducted herein is leveraging prior efforts conducted at GT which relate the physical changes at the aircraft level to changes in input parameters to the AEDT Fleet DB, and subsequently the output results of AEDT in terms of fuel burn, emissions, and noise and other metrics of interest to the FAA.

## Task 1 Proper Uncertainty Definition of AEDT Input Parameter

### Objective(s)

The objective of Task 1 is to identify the uncertainty of the key AEDT input parameters that may impact the key environmental metrics being calculated by AEDT. Prior research is reviewed to understand the approach used, results, and lessons learned. Based on the findings from the prior research and the discussions with the sponsor, the clear scope of the research is defined. The outcome of this task is a list of AEDT input parameters that will be taken for Tasks 2 and 3 along with the probability distributions associated with them. In addition, physical correlations among input parameters are defined in this task.

### Research Approach

#### Review of Prior Works

During the development of AEDT, two major research efforts have been undertaken in the past related to parametric uncertainty quantification of AEDT. The most recent work was on AEDT 2a, which resulted in AEDT 2a UQ Report and AEDT 2a SP2 UQ Supplemental Report in 2014 (Refs. [1] and [2]). Another major effort was made on parametric uncertainty quantification of AEDT alpha in 2010 (Refs. [3], [4], [5], [6]). The GT team has reviewed the documents and held a teleconference with the Volpe personnel who had lead the AEDT alpha and 2a UQ studies. Based on the understanding of the approaches taken, datasets used, and the results observed, the GT team has proposed the scope and approach for the AEDT2b UQ effort as summarized in Table 1 through telecons with the FAA Project manager.

*Table 1 Summary of Previous Studies and Comparison to GT Approach*

| | Previous Studies | GT Approach |
|---|---|---|
| Analysis Scope | • Fleet level at 1~5 Airports | • **Assess UQ at an aircraft level for various aircraft types** (first 6 months)<br>• Fleet level (optional) |
| Approach | • Combined impacts of inputs varying together | • Show impact of **individual input changes** to outputs<br>• Show combined impacts |
| Output Parameters | • LTO fuel burn and emissions<br>• Noise | • **Full gate-to-gate fuel burn and emissions**<br>• LTO fuel burn and emissions<br>• Noise |
| Input Parameters | • Vary input parameters independently | • **Capture physical relationship among input parameters** |

**Uncertainty Characterization**

In order to characterize the sources of uncertainties that contribute to uncertainties in AEDT outputs, it is important to understand the context in which AEDT is utilized for the purpose of environmental impact assessments. GT has been either or both developing and utilizing various FAA's environmental tools such as EDS, GREAT, APMT-E, and AEDT. Specifically, GT has been performing technology and policy impact analyses for the US FAA modeling vehicle technology and design changes in EDS, propagating its vehicle level impacts into the fleet level impacts in AEDT.

GT will leverage prior research conducted and coefficient data generated under PARTNER Project 14 and 36. Under these projects, a number of engine/airframe combinations were developed and validated directly to the AEDT definitions and performance. As such, a consistent approach was developed to quantify changes at the vehicle level to changes in the outputs of the AEDT modeling environment. This full definition includes all aspects of BADA and SAE AIR-1845, including detailed takeoff and landing procedures, noise, etc. which is consistent with the output results of the AEDT Fleet DB representation as documented in numerous PARTNER annual reports since 2007. This aspect is imperative for the current research since changes in the aircraft or engine design are parametrically linked to Fleet DB coefficients, thereby changing the performance in AEDT. This process is the fundamental driver of the uncertainty analysis.

In prior analyses, GT developed a comprehensive approach translating a vehicle definition in EDS to a representation in the AEDT Fleet DB and also testing the vehicle on representative missions that mimic the way aircraft are flown in AEDT. GT developed a batch mode version of AEDT core logic that is executed when EDS runs so as to ensure that the AEDT representation of an EDS model is in line with an equivalent aircraft in the Fleet DB. This tool is called the "AEDT tester" and was provided to Volpe. The tester also allows for running vehicles that are within the Fleet DB. As surrogate models for GREAT and or the generic fleet were developed over the years, a plethora of data of the AEDT Fleet DB coefficients were generated and in addition output results from the AEDT tester. This data, and the models from which it was created, serves as the basis to understand the uncertainty associated with variations in aircraft design to the changes in the coefficients and sequentially to the changes in the AEDT output results.

In addition, GT has used the EDS/AEDT toolset for the purposes of modeling and evaluating NASA's ERA technology portfolio. NASA's ERA technology portfolio targets mid-term technology solutions including unconventional airframe and engine architectures of open rotor being integrated into hybrid-wing-body (HWB) airframe in 300 passenger class. GT will collect AEDT input and output parameters from ERA vehicles to compare the statistics with the data obtained from PARTNER Projects 14 and 36.

The AEDT input file for each of the aircraft models generated through EDS is in an xml format. In order to parse key AEDT input parameters from the xml files, a python script has been written. Running the script, the GT team has collected about 30 AEDT input parameters for about 900 EDS aircraft in large single aisle (LSA) class. The preliminary analysis was performed on LSA aircraft from PARTNER Project 14. In Project 14, the baseline EDS LSA aircraft was varied by changing aircraft and engine design parameters for the purpose of creating a generic vehicle (GV) that represents environmental footprints of major LSA aircraft fleet including Boeing 737 and Airbus A320 families.

As an example, the geometry and technology level of a 150 pax aircraft were varied and the calculated coefficients are depicted in Figure 1. The scatterplot shows the physical correlations for a very small subset of the coefficients needed within the Fleet DB. Each dot on the right represents a specific definition of an aircraft. When a clear trend exists in a panel between two variables (i.e. COEFF_CF1 and COEFF_CF2 are positively correlated), this implies a physical correlation between the two which must be accounted for during the uncertainty propagation. In the previous AEDT UQ studies, these distributions on the left were sampled independently and usually as either a triangular or uniform distribution. When strong correlations among input parameters are ignored, a sampled set of inputs can created a physically infeasible case. As such, this task will result in the collation of prior analysis conducted at GT to properly define the input distributions and the physical correlation between them to establish the uncertainty representation of the inputs to AEDT. Each of these prior analyses utilized various accepted statistical sampling techniques, for which numerous mathematical uncertainty quantification techniques will be utilized in Task 2 to relate the variability of inputs to AEDT outputs.

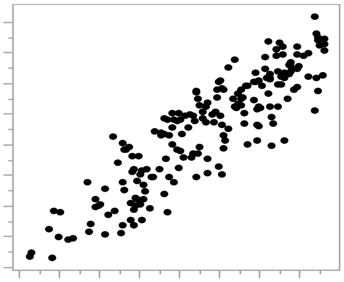

*Figure 1 BADA Fuel Flow Coefficients from EDS LSA Aircraft*

## Milestone(s)

Since the project is in its early phase, the GT team is conducting literature review, data collection, and data analysis under Task 1. The team had a kickoff meeting with the FAA on August 5, 2015. The GT team and the FAA held a teleconference on August 31, 2015 and GT has submitted a monthly report on that day. GT/FAA/Volpe had a subsequent teleconference on September 15, 2015 to discuss AEDT2a and AEDT alpha UQ work conducted by Volpe in 2014 and 2010 time frames. The GT team also presented its work to the FAA external tools team on September 22, 2015.

## Major Accomplishments

Since the project is in its early phase, the GT team is conducting literature review, data collection, and data analysis under Task 1. The team has shared the plan and preliminary results in various meetings with the US FAA, Volpe, and the external tools team.

## Publications

None

## Outreach Efforts

None

## Awards

None

## Student Involvement

Fatma Kargoz, is a second year PhD student. As a Graduate Research Assistance, Fatma has been writing Python scripts to parse AEDT input parameters from AEDT input files.

Evanthis (Eva) Kallou is a first year PhD student who started in fall 2015. As a Graduate Research Assistance, Ms Kallou has conducted literature review on UQ methods. Ms. Kallou is being trained on related tools such as AEDT Tester and AEDT2b.

Junghyun (Andy) Kim is a first year PhD student who started in fall 2015. Mr. Kim has conducted literature review on UQ methods. Mr. Kim is being trained on related tools such as AEDT Tester and AEDT2b.

Matthew Levine is a PhD student, anticipated graduation in December 2015, and has served as a collaborator on this project due to his experience with AEDT and EDS and the data utilized in this project.

## Plans for Next Period

GT is planning on finalizing Task 1 in early October 2015. However depending on the outcome of Task 2, it is possible to revisit this task and update the analysis. GT will continue the project conducting Tasks 2 and 3. Brief descriptions of the future tasks are provided here.

**Task 2 – Identification of Important Output to Input Relationships**
The outcome of this task will be an identification of the key input drivers across multiple vehicle types to multiple AEDT metric outputs to provide a comprehensive insight to the uncertainty associated with AEDT and the and joint-distribution shapes between Fleet DB coefficients. Various uncertainty quantification mathematical techniques will be used depending upon the metric of interest and the most intuitive means for communicating the results to the FAA. This may include, but not be limited to the following techniques: Analysis of Variance (ANOVA), Multivariate Analysis of Variance (MANOVA), Monte Carlo Simulation, or Copula Techniques.

**Task 3 – Guidelines for Future Tool Research**
Finally, each of the prior tasks will culminate into a summary document of the data assumptions, techniques utilized, and the resulting observations to help guide the FAA in the areas of further research in the development of AEDT and its supporting data structure and algorithms.

This document can also serve as a guidance material for various aircraft design tools as they seek to connect to the AEDT Fleet DB data structure. This will allow for the identification of specific coefficients that are more important in terms of the level of accuracy needed from that specific aircraft design tool. This is of significant importance as AEDT 2b seeks widespread use within the aviation community.

## References

[1] US FAA, *AEDT 2a UQ Report*, 2014
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